ANDERSON & ARNOLD

Investigation of Ground Connections

Electrical Engineering

B. S.

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INVESTIGATION

OF

GROUND CONNECTIONS

BY

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THESIS

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190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ENTITLED

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF

O.B. Wooten,
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APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF Electrical Engineering

Introduction.

Up to the present time very little investigation has been made in regards to ground connections in electrical work, and, therefore, no reliable information is available for this important phase of electrical engineering.

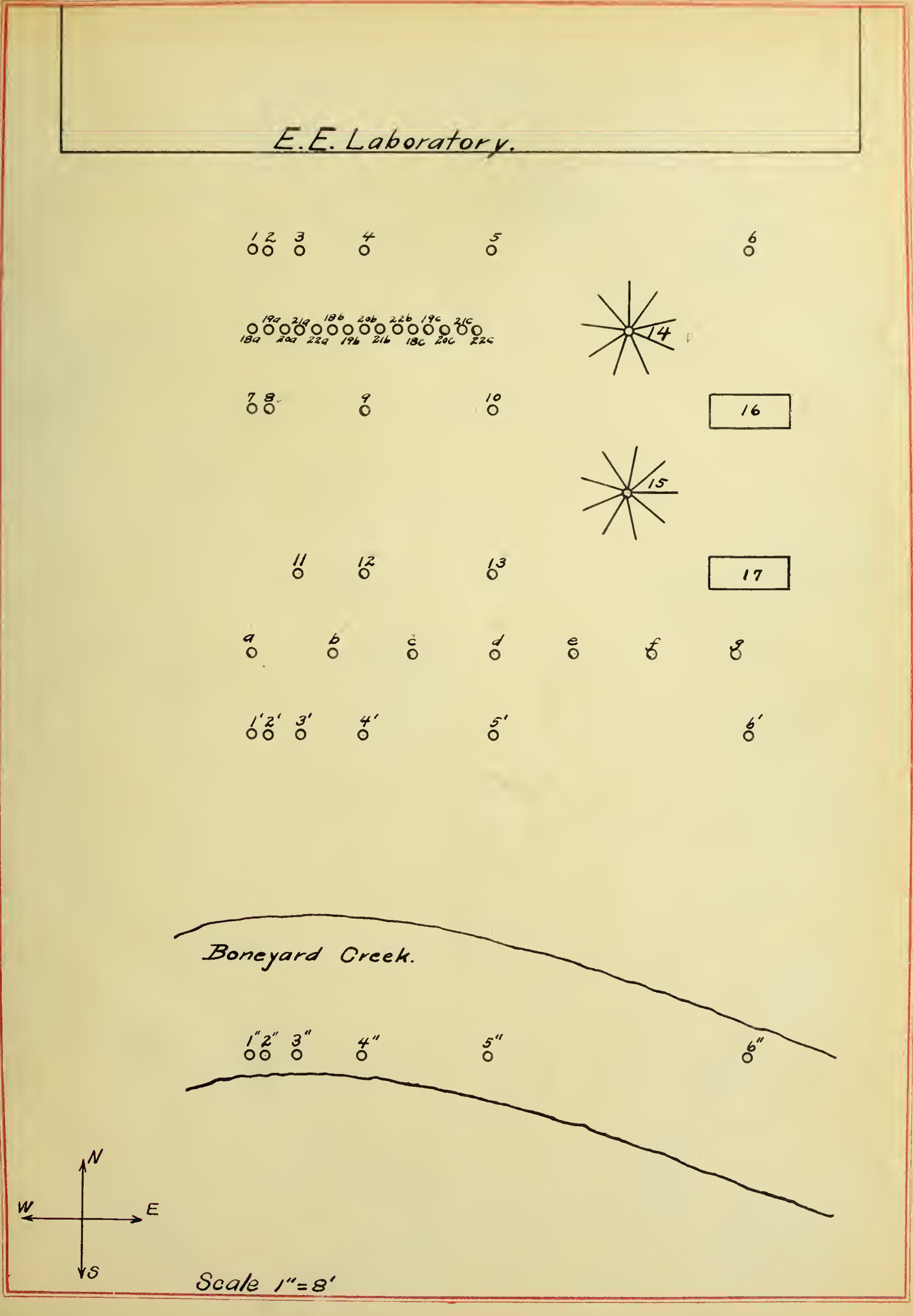
The writers of this work have endeavored to make a study of ground connections which are likely to exist under various conditions, and to determine the best manner of making these connections.

It must be remembered that many variables enter into work of this kind, and hence the conclusions drawn are only general and not specific.

The writers are indebted to Messrs Bell and Coe for valuable data secured in the spring of 1910. Thanks are also due Mr. Wooten for his kind assistance and helpful suggestions.

Description of Grounds.

For this experimental work, the plot of grounds lying directly south of the Electrical Engineering Laboratory was chosen. The earth is partly natural and partly made. Black loam forms the upper two and one-half to three feet, that near the surface showing signs of having been graded in. Below the loam is a stream of yellowish blue clay from six to eight inches in depth. Beneath this, the soil is common blue clay.



E.E. Laboratory.
1 2 3 4 5 6
19a 21a 18b 20b 22b 19c 21c
18a 20a 22a 19b 21b 18c 20c 22c
14
7 8 9 10
16
15
11 12 13
17
a b c d e f g
1' 2' 3' 4' 5' 6'
Boneyard Creek.
1" 2" 3" 4" 5" 6"
N
W
E
S
Scale 1" = 8'

The grounds were laid out according to diagram and the following arrangement of ground connections chosen.

Number	Kind of terminal	Length in feet.	Kind of point.
1	Pipe	4	Sharpened
2	"	4	Plain
3	"	4	"
4	"	4	"
5	"	4	"
6	"	4	"
1'	"	4	"
2'	"	4	"
3'	"	4	"
4'	"	4	"
5'	"	4	"
6'	"	4	Sharpened
1"	"	4	"
2"	"	4	Plain
3"	"	4	"
4"	"	4	"
5"	"	4	"
6"	"	4	"
7	"	1	"
8	"	2	Sharpened
9	"	6	Plain
10	"	8	"
11	"	4 salted	"
12	"	6 "	"

Number	Kind of terminal	Length in feet.	Kind of point.
13	Pipe	8 salted	Plain
g	"	1	"
f	"	2	"
e	"	4	"
d	"	6	"
c	"	8	"
b	"	10	"
a	"	11-1/4	"

Plain pipes were those with a circular cross section throughout. The sharpened pipes were plain pipes which had been heated and then one end mashed to a point.

Number 14 is a pipe four feet long, plain joint, with nine number four B and S gage wires, three feet in length, fanned out from the bottom.

Number 15 is a four foot pipe, plain point, with nine number twelve B and S gage wires, three feet in length, fanned out from the bottom.

Number 16 is a copper plate, 2-1/2 by 5 feet by 1/64 inch thickness, buried in coke at a depth of 4 feet.

Number 17 is identical with 16 except without the coke.

The pipes used were the common wrought iron pipes, not galvanized, found on the market in standard sizes.

Work was commenced on the placing of the terminals during the latter part of January 1910 with the frost still in the ground. Considerable difficulty was met in driving

these pipes due to the condition of the ground and to the joints of the pipes in most cases being plain.

Pipe number 5 was split in driving so was drawn. The hole was then filled, tamped, and a new pipe driven. Pipes number 1, 2, 3, 4, 5, 6, 1', 2', 3', 4', 5', and 6' were all driven the same day, but the ground near the "bone yard" was frozen deeper than that near the laboratory and may account to a certain extent for the variation in the resistance of these series of pipes. The main reason, however, for the variation is that pipes 1, 2, 3, 4, 5 and 6 are affected by an adjacent water main.

Pipe number 13 struck a rock in being driven so the contact may be influenced by this.

In locating number 14 and 15, four foot holes were dug, the pipe and fan put in place and the earth replaced, tamped, and watered.

Number 16 was dug up during the summer for repairs and on replacement the earth could not be packed as tightly as before; consequently there was a mound about eighteen inches high around the surrounding ground.

The copper plates, number 16 and 17, were fitted with terminals by soldering number eight B and S gage copper wire to the centers of the longer sides, near the outer edges, and running them across to the centre of the plate, being soldered the entire length. The joints were covered with two coats of paint, acid and water proof, to prevent electrolytic action. They were buried in the manner of number 14

and 15, except seven bushels of coke screenings were packed around number 16, giving a three inch layer of coke all about the plate.

Groups number 14, 15, 16, and 17, at a depth of four feet, lie in the stratum of blue clay mentioned above.

Pipes number 10, 11, and 12 were driven to be used for salt tests, but data was first taken on them as for other pipes.

The pipes numbered from 18a to 22c were driven on April 8, 1910. They are spaced one foot apart, are all four feet in length and range in sizes as follows:-

Numbers			Diameter
18a	18b	18c	3/8"
19a	19b	19c	5/8"
20a	20b	20c	1"
21a	21b	21c	2"
22a	22b	22c	3"

A hole was tapped near the upper edge of each pipe and a pipe plug, bearing about six inches of number twelve copper wire, screwed in. A brass terminal was soldered to the ends of the wires similar to that on the end of a volt-meter lead.

A series of pipes were driven, extending in a north-westerly direction and reaching to Wright Street, with the purpose of testing the variation of resistance with distance. Steam mains, however, so interfered that the readings were worthless for this purpose. The resistance for the first

few feet distance increased, as was to be expected, then the value decreased gradually, and finally began increasing again.

Method of Operation

The theory connected with this work is an application of Ohm's Law $I = \frac{E}{R}$, where I represents the current, E the impressed voltage, and R the resistance. The inductance of the earth is negligible. A constant current of six amperes was always maintained whenever possible.

In the continuous readings simple series connections were made to each pipe, the return being a water main entering the east side of the storage battery room. Alternating current was used in order to do away with polarization effect.

Elimination of Errors.

Corrections were made for voltmeter readings by means of calibration scales for instruments in use, whenever the error was large enough to warrant such correction. The ammeter used read correctly.

All curves, except continuous, were plotted from the average value of several readings. No curve has been plotted from one single set of readings.

No correction was made for the resistance of the lead wires since it was negligible. The work is not accur-

ate enough to carry any calculation greater than .1 of an ohm.

Variations of voltage probably caused error in several readings. There is, however, no method of correcting for this.

Outline of Curves

Curve I.

Variation of resistance with depth of pipe.

Curve II.

Variation of resistance with diameter of pipe.

Curve III.

Variation of resistance with distance between two similar pipes in parallel.

Curve IV.

Variation of resistance with distance, pipes in series.

Curve V.

Variation of resistance with time after salting.

Curve VI and VII.

Tests with direct current.

Curve VIII.

Test with direct current, water poured in pipe.

Curve IX.

Alternating current continuous test, water poured in pipe.

Curve X.

Variation of resistance with time of year, short pipes.

Curve XI.

Variation of resistance with time of year, long pipes and plates.

Curve XII.

Curve verifying Curve I.

Curve XIII.

Curve showing variation of resistance with depth, salted pipes.

Results.

Curve I.

This curve shows that the resistance decreases very rapidly with increasing depth of pipe up to the length of about four feet. For pipes longer than six feet, the resistance decreases very slowly, and after a depth of about twelve feet would probably be nearly constant. This is due, in part, to the difference in area of contact, but the fact that the short pipes are buried in the upper loose loam also accounts for the higher resistance. The curve seems to show that clay is not a good conductor. If such were the case, there would be a sudden break downward in the curve instead of the curve being practically horizontal.

Curve II.

Here the effect of size of pipe is shown, the larger the pipe the less the resistance, due to the greater area of contact. The decrease of resistance, however, does not continue indefinitely. It decreases quite rapidly up to a diameter of two inches, after which it decreases very slowly

and would probably have become constant with larger diameters.

Curve III.

These curves for parallel circuits show that the resistance decreases rapidly with increase of distance between pipes, up to about eight feet, after which the decrease is slow and gradual, and would probably become constant eventually. This is due to the greater drop in the earth when the circuits are close together. The current density varies inversely with the distance between terminals, caused by the interference of flow lines between pipes.

Curve IV.

For series circuits the ground resistance increases rapidly up to about ten feet after which it becomes nearly constant. This result is verified by the data taken for two separate sets of pipes in different parts of the plot of ground. An interesting part here is that those pipes near the "Boneyard" have a resistance of about twice those near the laboratory. This is probably due to location of the water main.

Curve V.

The effect of using artificial means to increase the conductivity of the earth and contact, is well shown by these curves. The resistance of the pipes after being salted immediately falls several ohms. The decrease of resistance is rapid for the first several minutes, more gradual for the next couple of hours, and about constant from then on.

On April 27, 1911, pipes number 6' and 11 were dug up and examined. Pipe 11 was salted, but 6' was not. The

Salted pipe was slightly corroded,but the other had not been effected.

Curve VI and VII.

These curves show the effect of continuous use of direct current. The increase of resistance is very gradual for the first hour, after which it increases very rapidly for a considerably longer time.

Curve VIII.

This curve shows the same results as VI and VII, and in addition shows the effect of pouring in water. The water moistens the earth thoroughly, increases the conductivity, and hence decreases the resistance.

Curve IX.

This curve shows the effect of using an alternating current continuously, then increasing the conductivity by pouring water in the pipe. It will be noticed that the resistance decreases slowly for about an hour, then increases very rapidly. This condition is probably brought about by the chemical action of the salts in the soil.

A three foot pipe with a number of holes drilled in sides was used for this test. The pipe was two inches in diameter and had sharpened ends to prevent dirt getting inside the pipe.

Curves X and XI.

Curve X shows that the resistance of short pipes is not at all constant but varies greatly with the season of the year.

Curve XI shows that all the pipes and plates are

affected by the time of the year, but not to such an extent as the one and two foot pipes in Curve X. The resistance increases with decrease of temperature, and decreases with rain fall.

The resistances of the pipes in all cases are much higher than those of the plates.

Terminals 16 and 17 are identical copper plates buried in the earth, number 16 being surrounded with a three inch layer of coke screenings. The resistance of both is quite uniform,that of number 16 being several ohms lower.

Pipe number 14 with the wires fanned out from the bottom and the salted pipe number 11 both remain fairly constant, the former, however, having the least resistance.

Curve XII.

This curve is simply a verification of Curve I.

Curve XII.

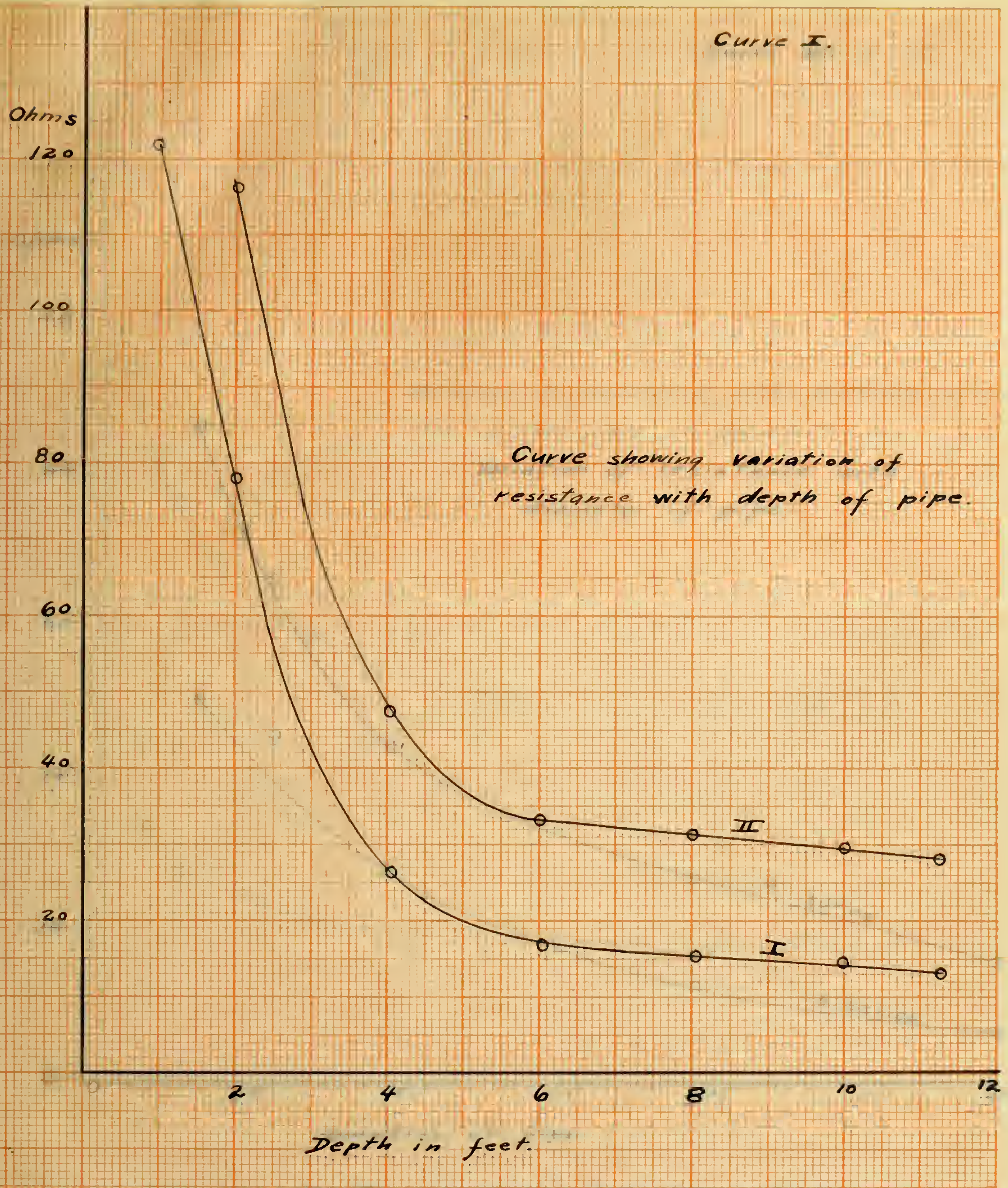
This is a curve showing the variation of resistance with the depth of pipe, the pipes being salted. Not enough data is available to enable any definite conclusions being drawn, only three depths being used. It would seem from the curve that the resistance decreases very slowly with the depth.

Conclusions.

The results show that the resistance decreases with:-

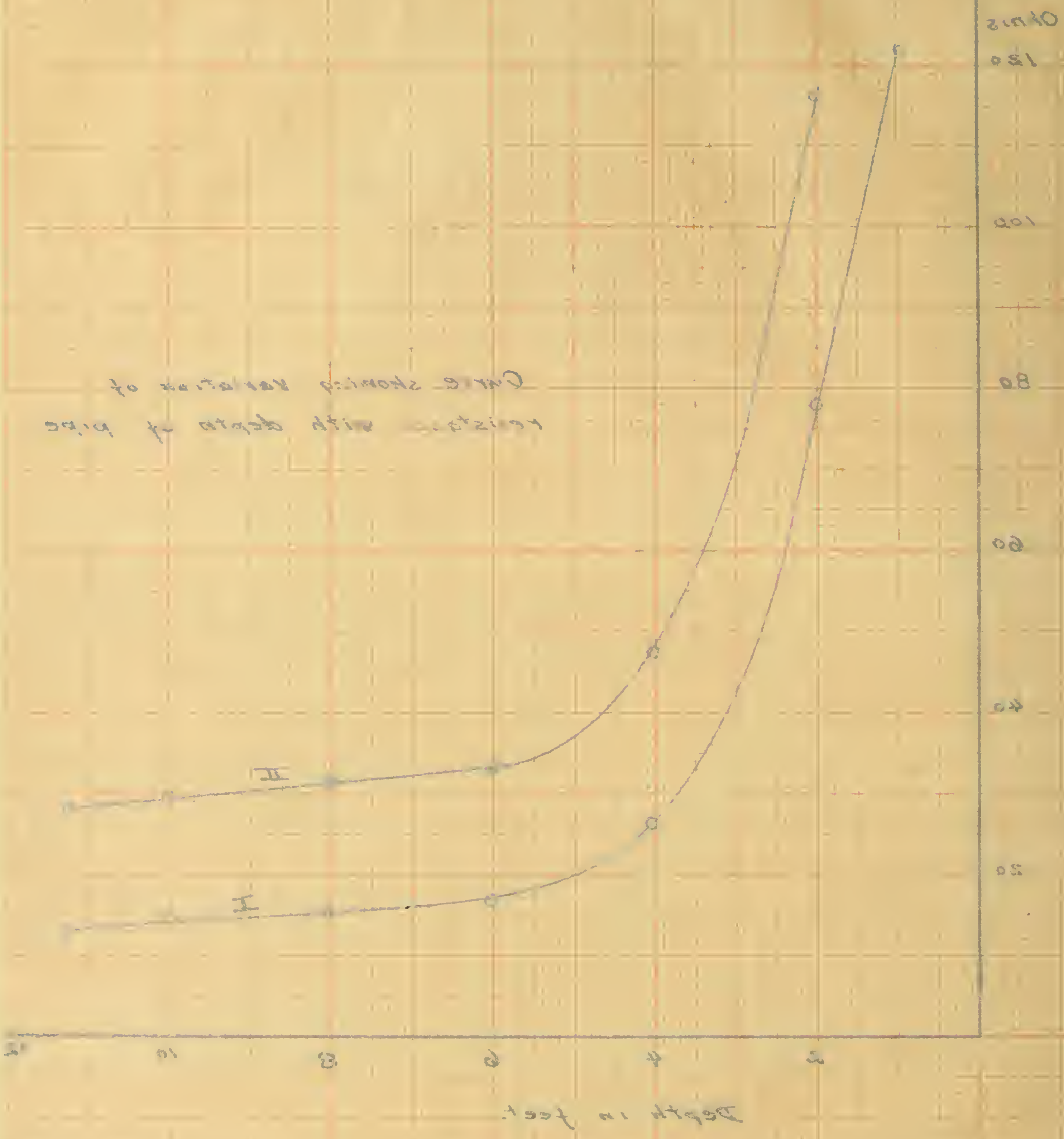
1. Length of pipe up to about twelve feet.
2. Diameter of pipe up to about three inches.
3. Distance between pipes in parallel up to about twelve feet.
4. The addition of artificial matter of high conductivity.
5. That the resistance increases with the distance between pipes in series up to about ten feet.

For a good cheap, efficient ground with resistance nearly constant. one such as number eleven would be very satisfactory. This is a plain, two inch, four foot pipe, salted. The resistance could be reduced still farther by using two such pipes in parallel at a distance of about eight feet.



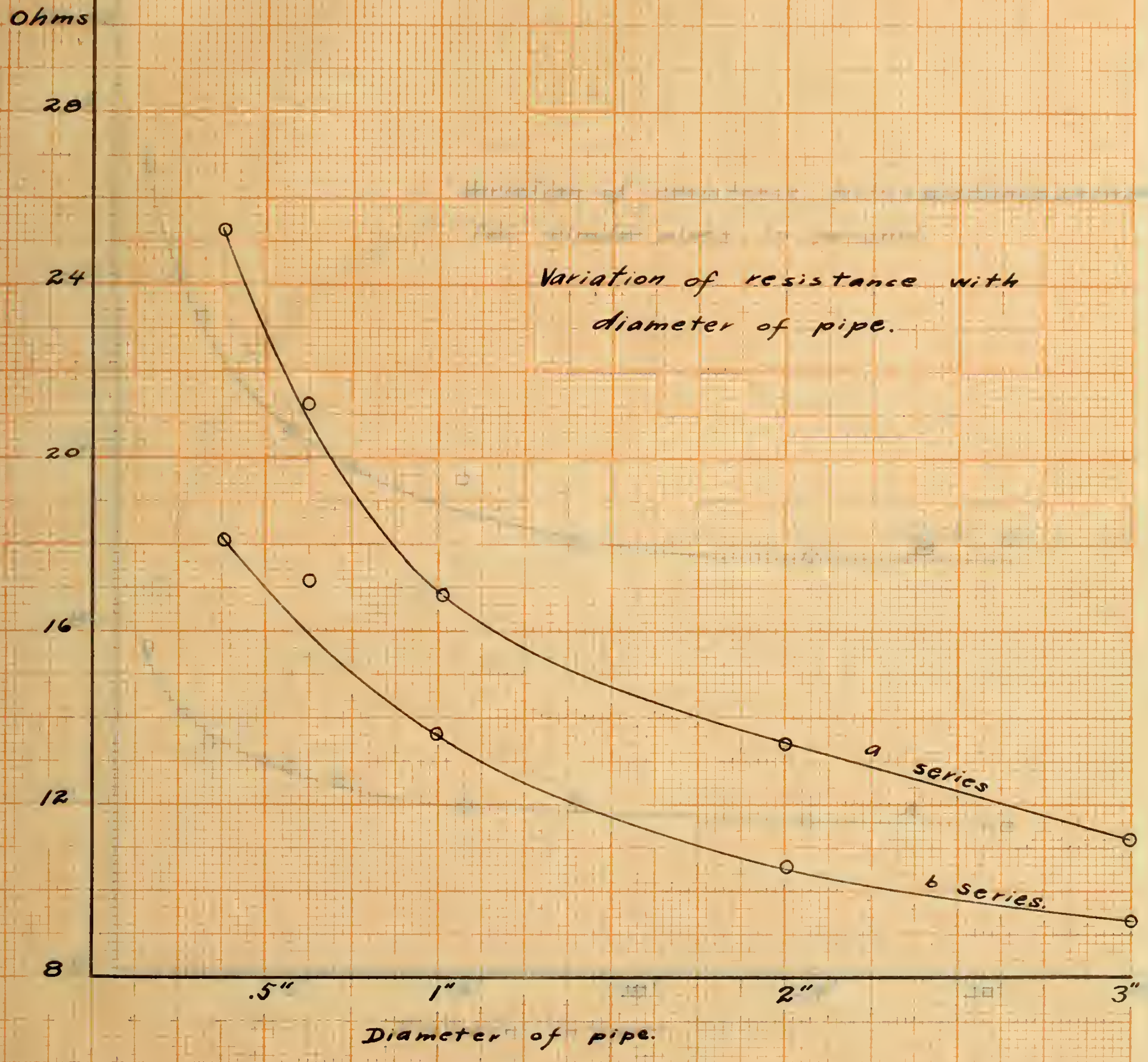
Curve I Water pipe as return.
Curve II Pipe #5 as return.

Curve X.

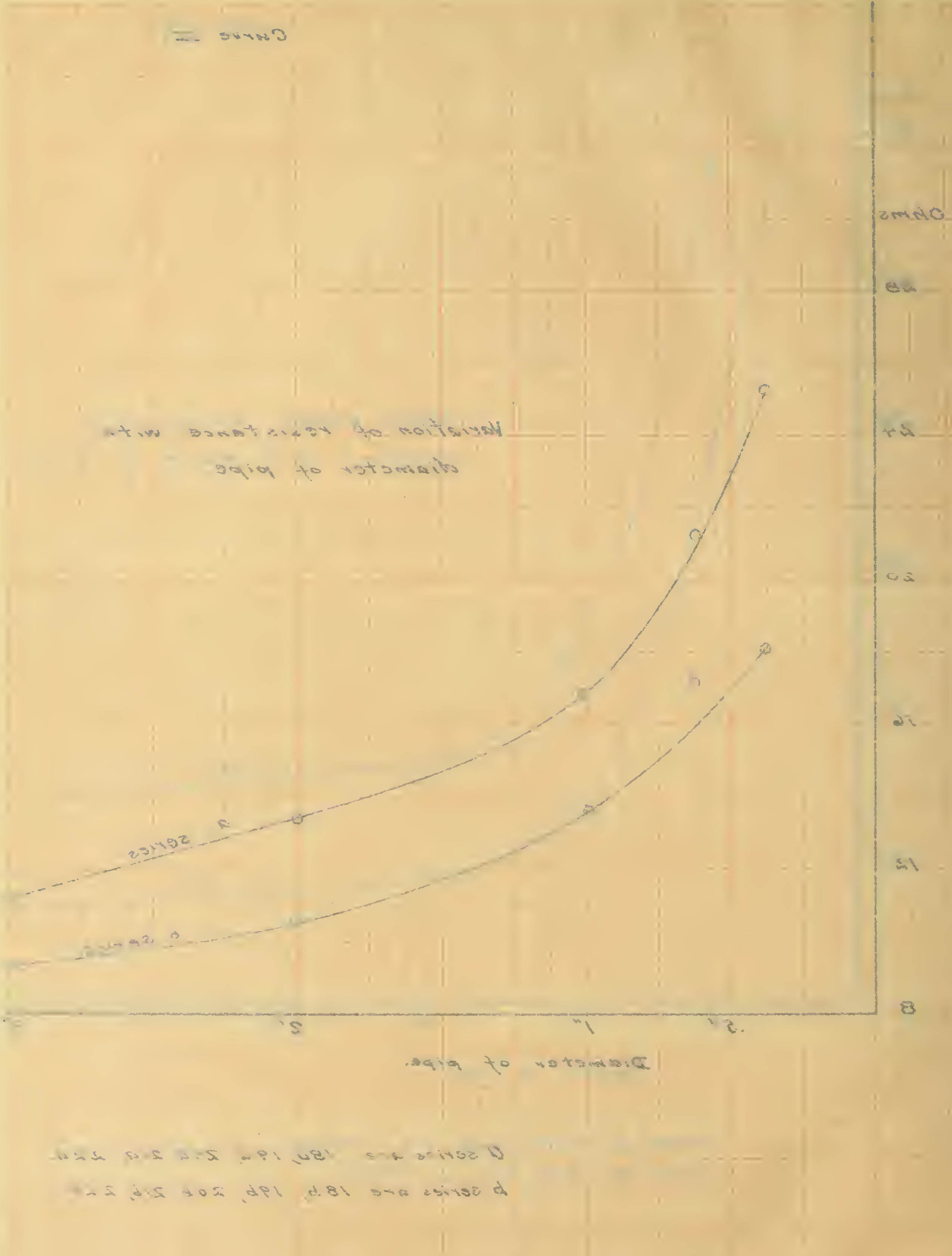


Curve I Water pipe as return.
Curve II Pipe #5 as return

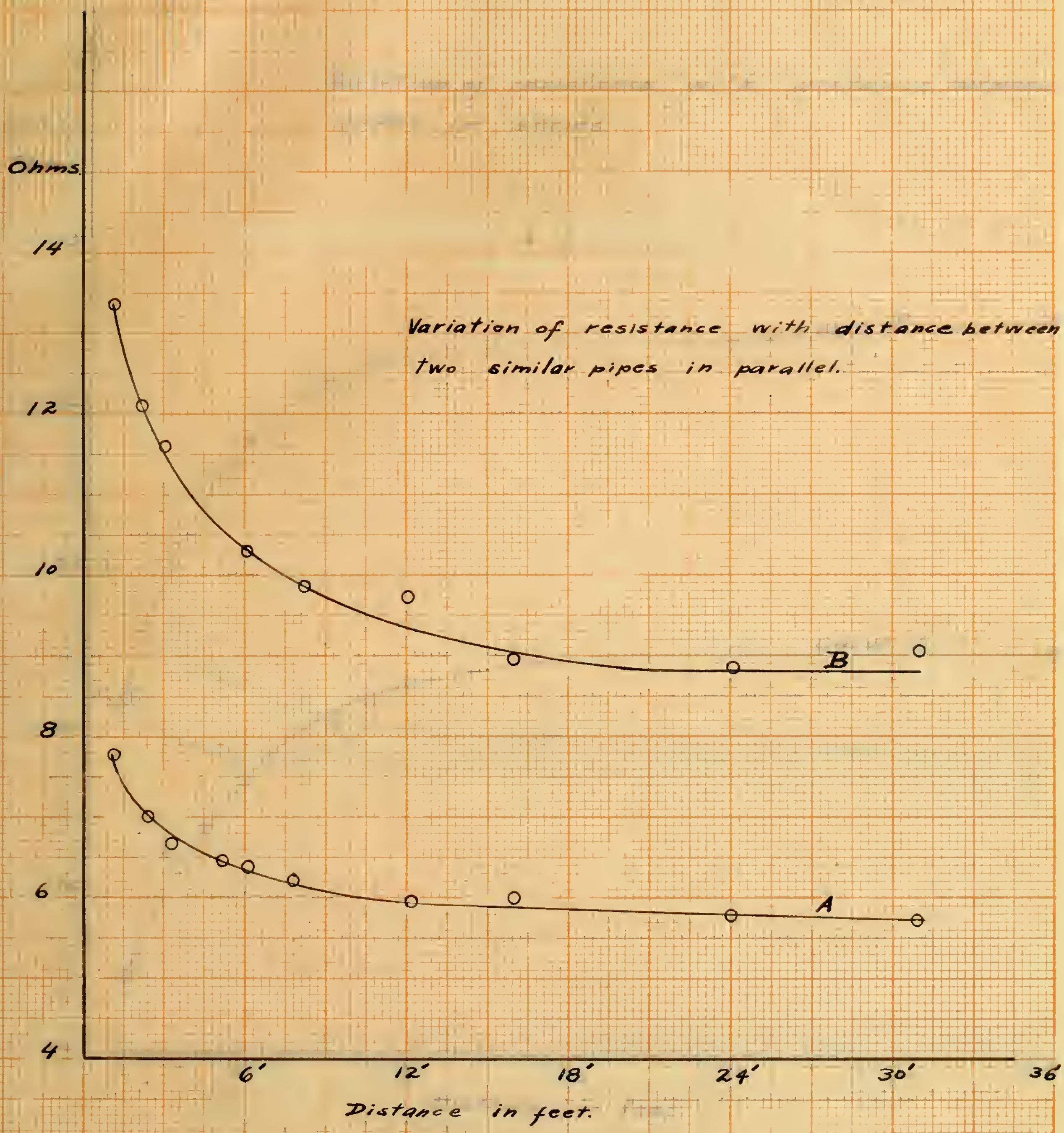
Curve II.



a series are 18a, 19a, 20a, 21a, 22a.
b series are 18b, 19b, 20b, 21b, 22b.



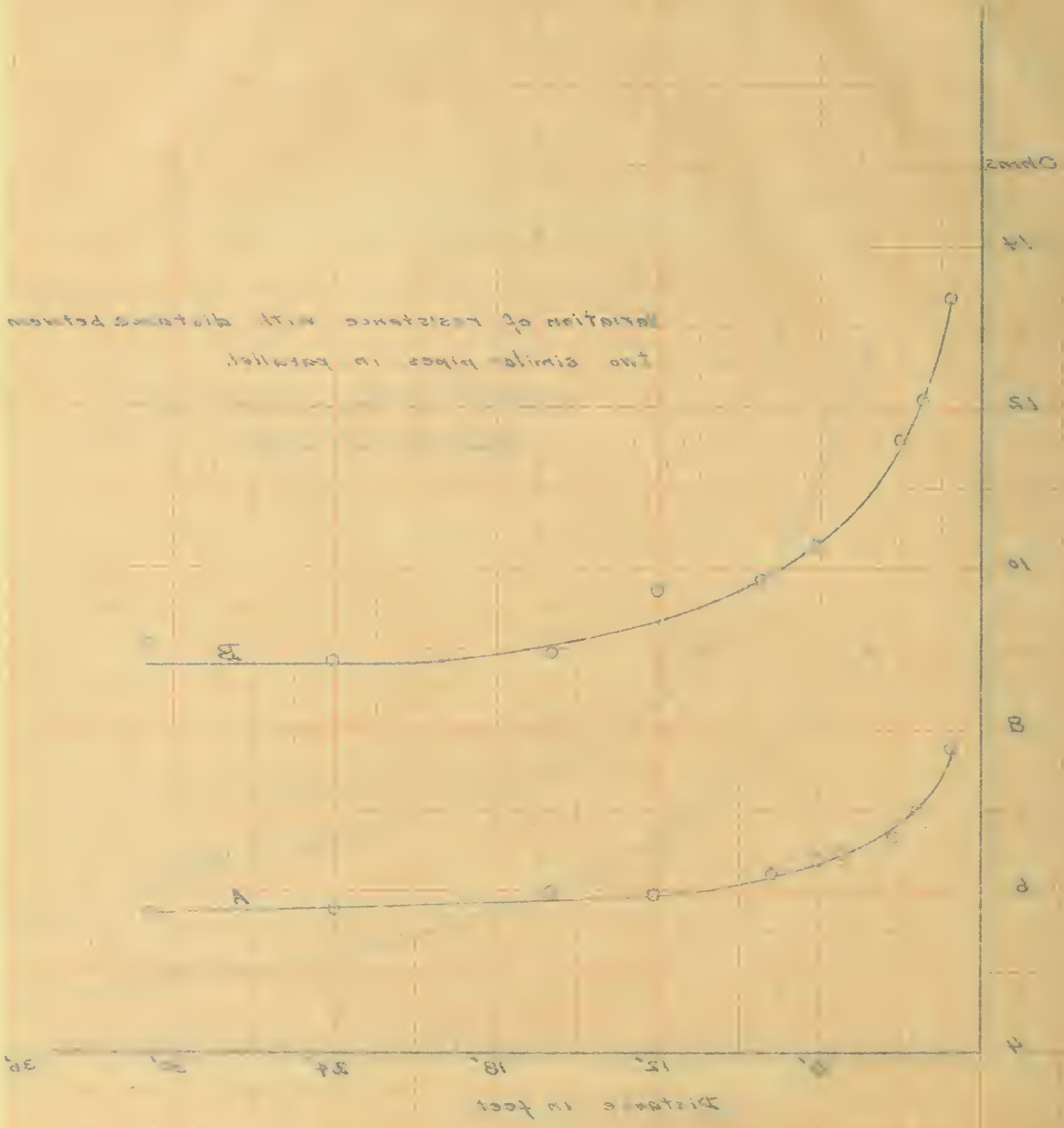
Curve III.



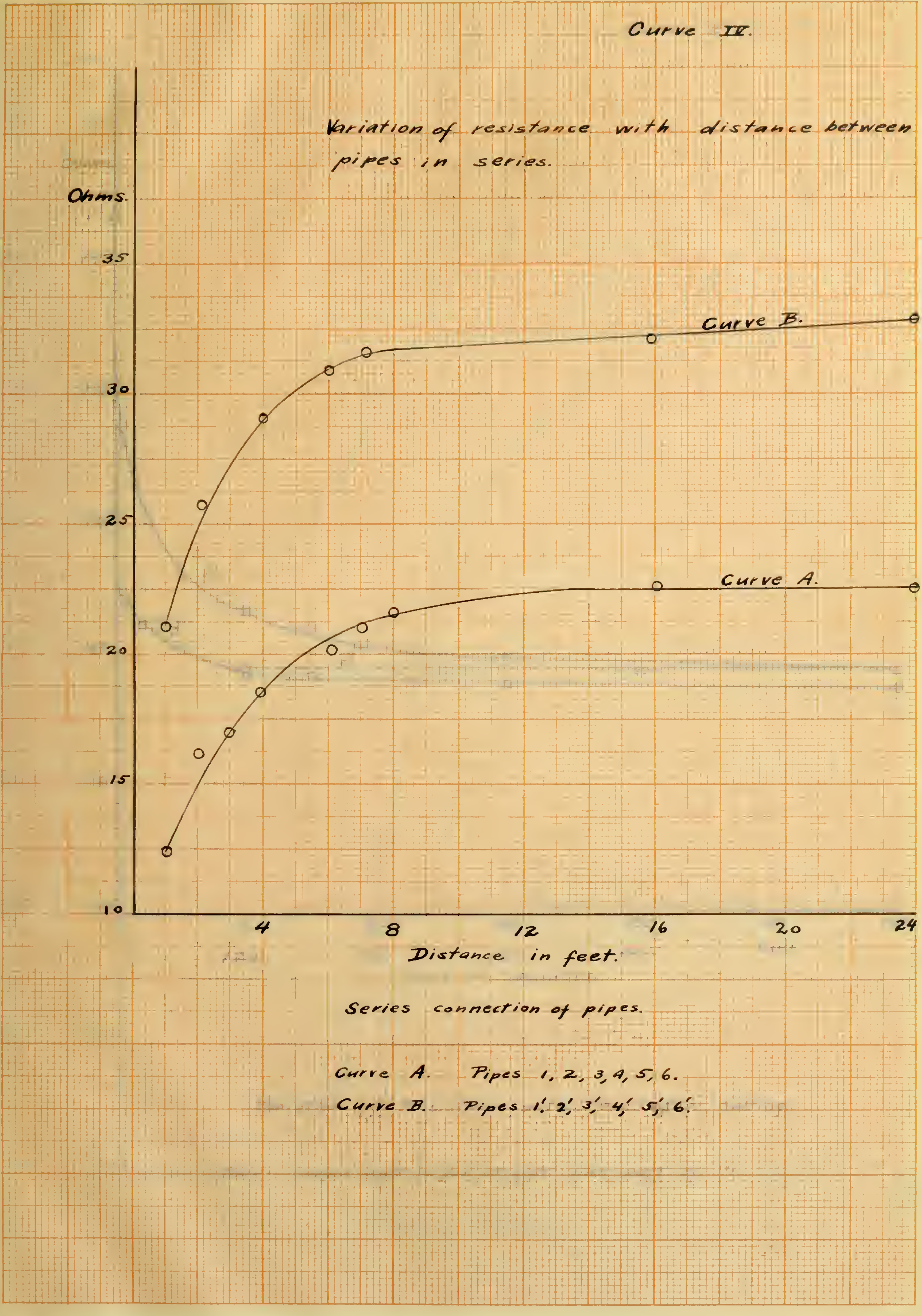
Curve A. Parallel connections with pipes 1, 2, 3, 4, 5, and 6.

Curve B. Parallel connections with pipes 1', 2', 3', 4', 5' and 6'.

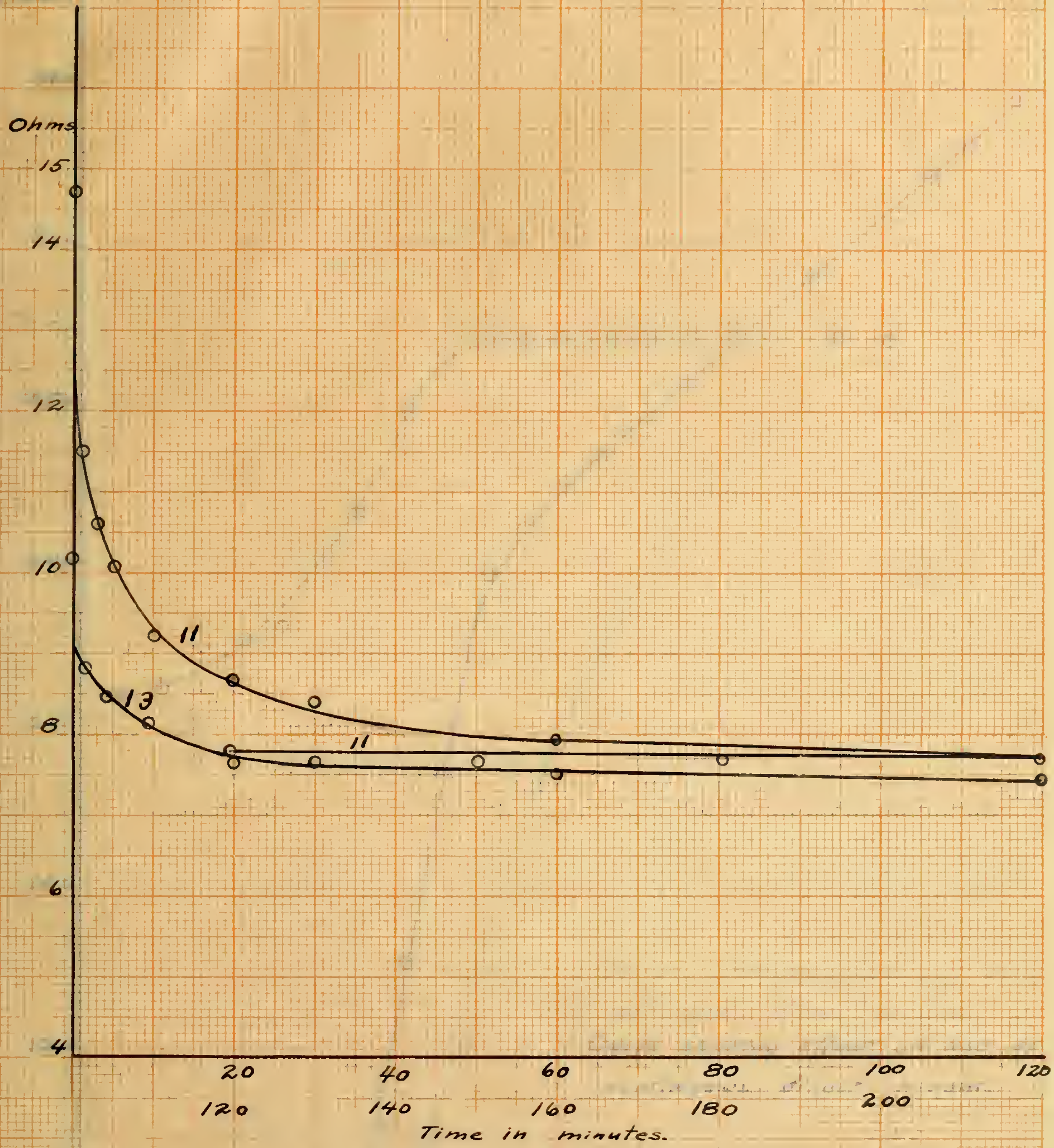
Curve IX



Curve A. Parallel connections with pipes 1 & 3 distance.
Curve B. Parallel connections with pipes 1', 2', 3', 4', 5' and 6'.


Curve IV.
Variation of resistance with distance between pipes in series.
Ohms.
35
30
25
20
15
10
Curve B.
Curve A.
4
8
12
16
20
24
Distance in feet.
Series connection of pipes.
Curve A. Pipes 1, 2, 3, 4, 5, 6.
Curve B. Pipes 1', 2', 3', 4', 5', 6'.

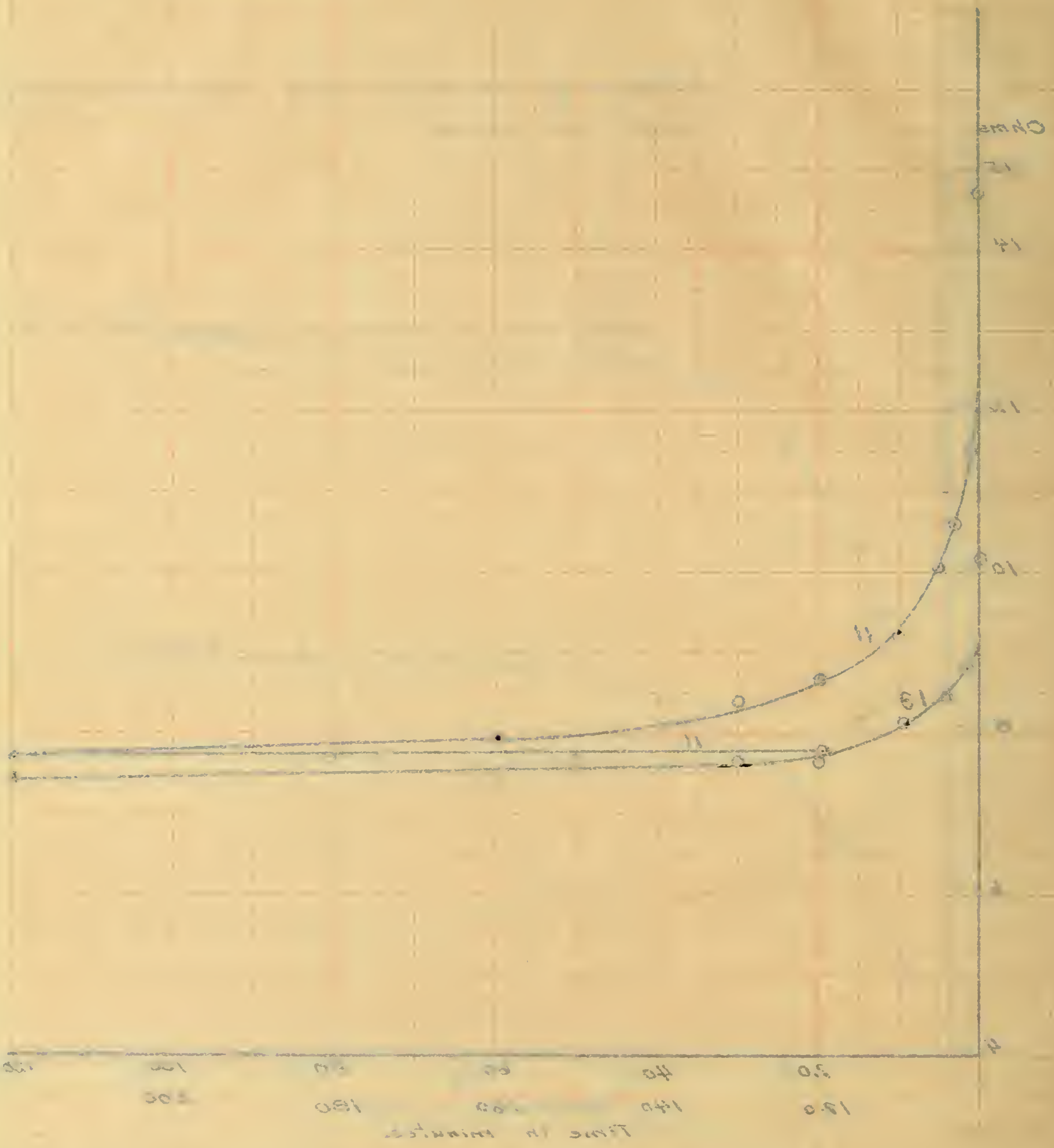
Curve V.



Variation of Resistance with time after salting.

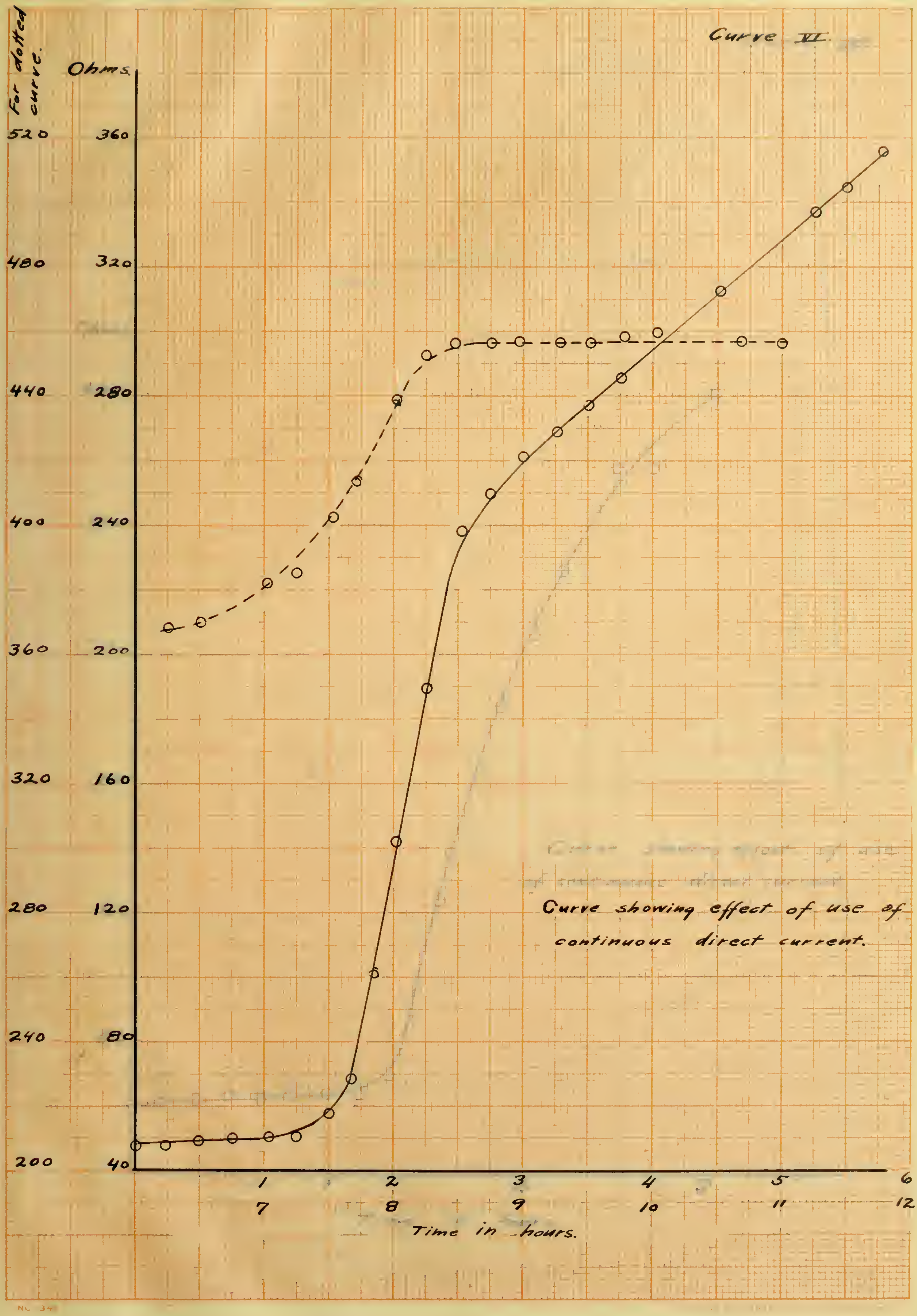
Note: Larger scale is for straight line part of 11.

Curve II.

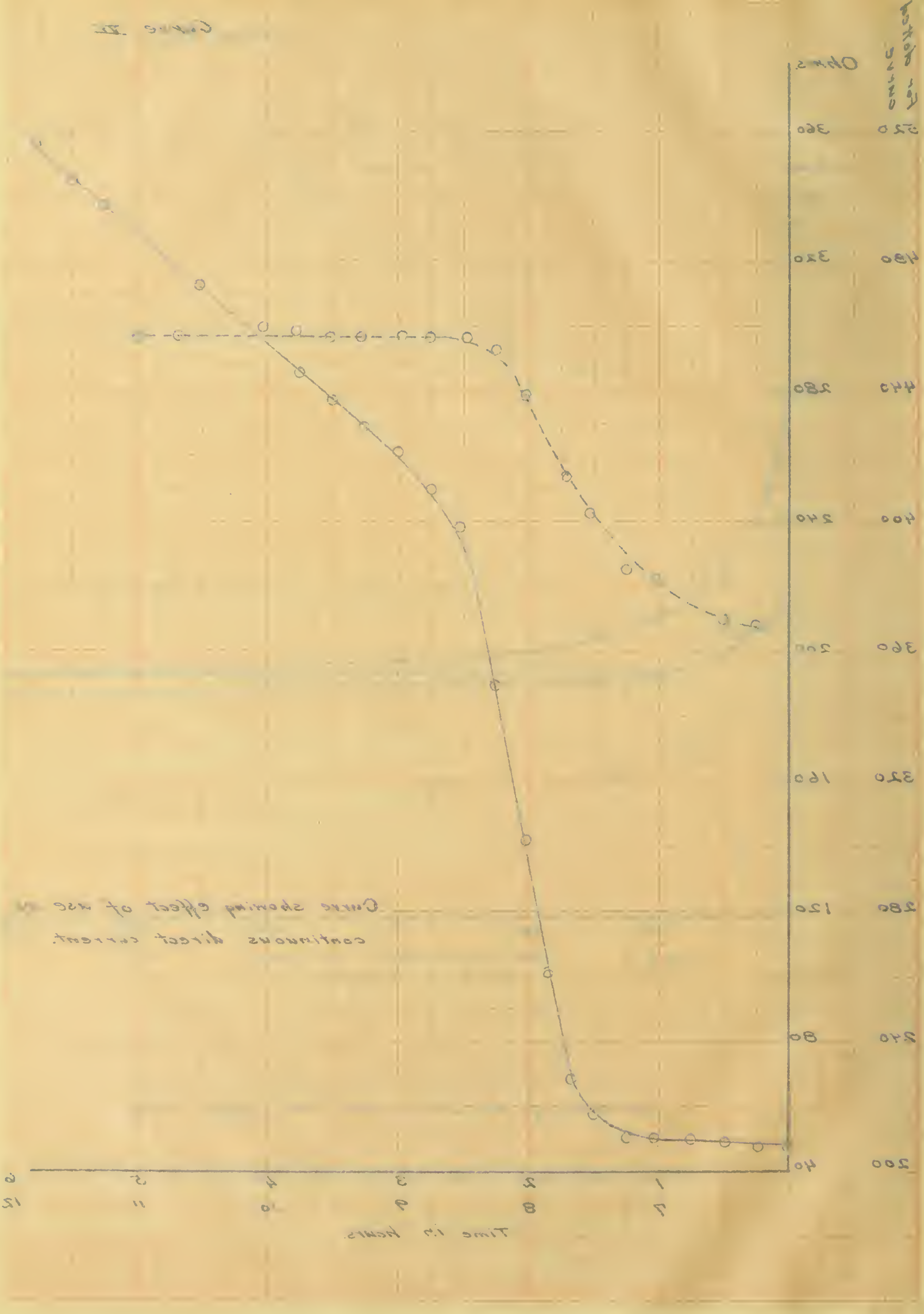


Variation of Resistance with Time after setting

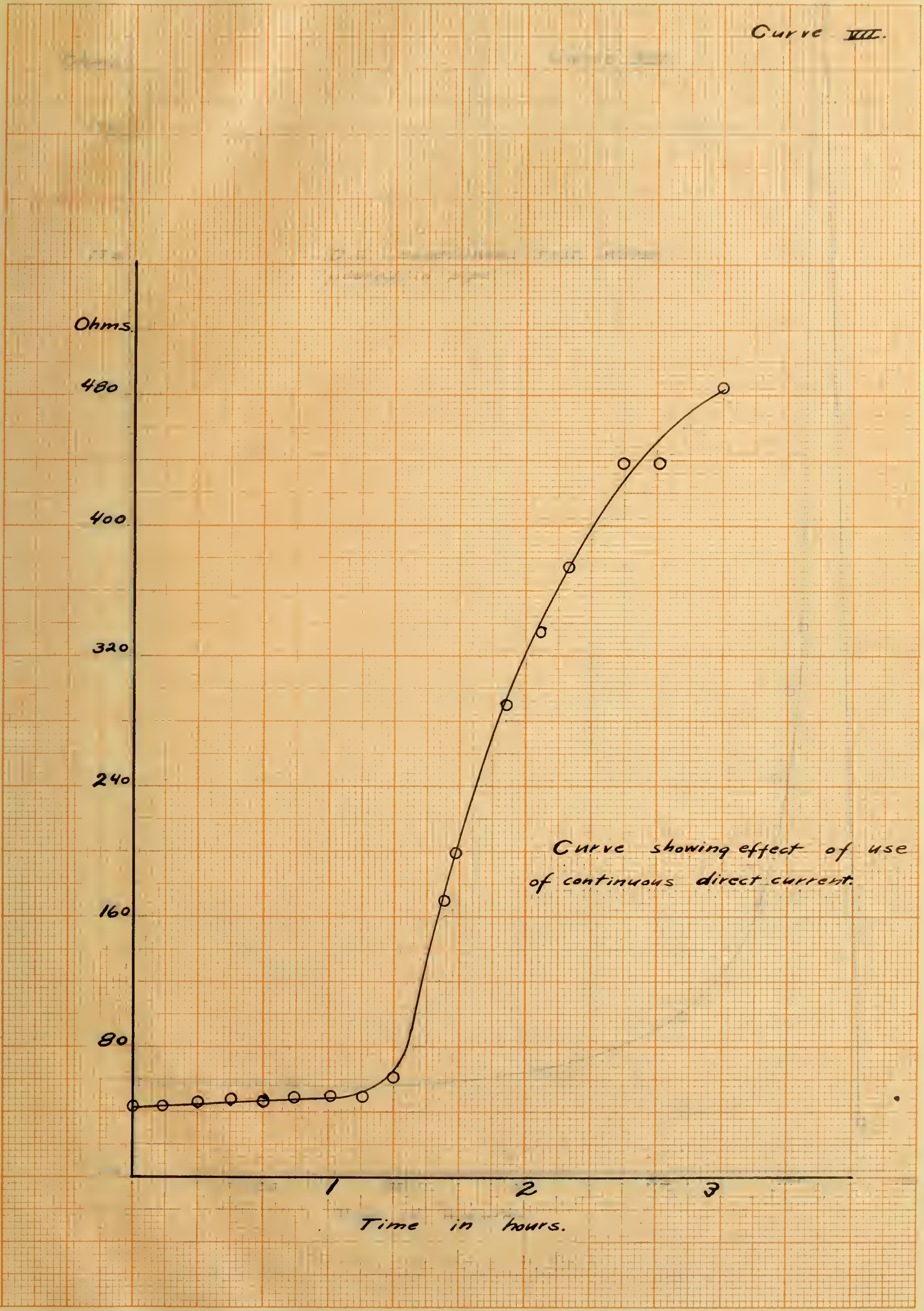
Note: Lower scale is for straight line part of 11.



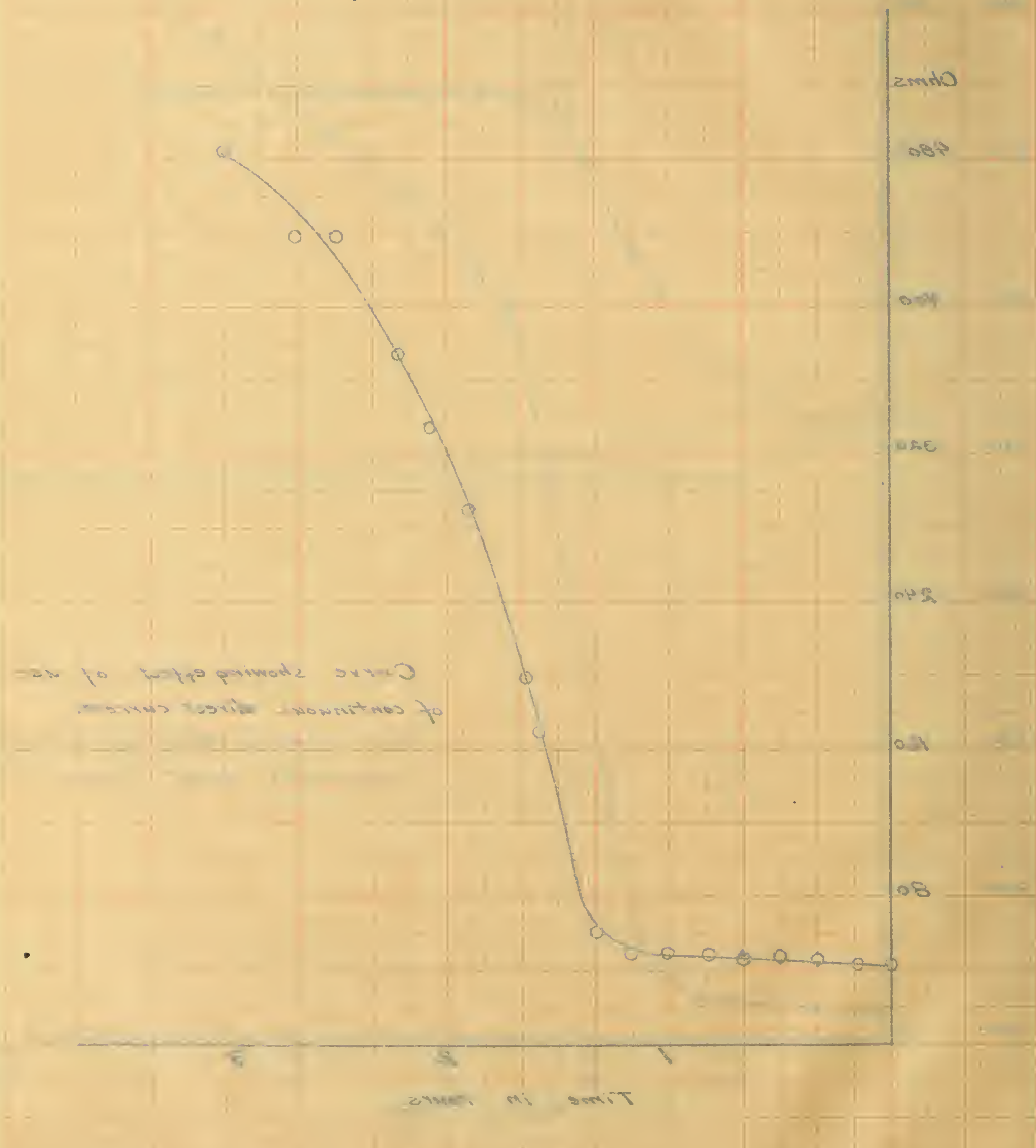
Curve VI.
For dotted curve.
Ohms.
520
480
440
400
360
320
280
240
200
360
320
280
240
200
160
120
80
40
1
2
3
4
5
6
7
8
9
10
11
12
Time in hours.
Curve showing effect of use of continuous direct current.

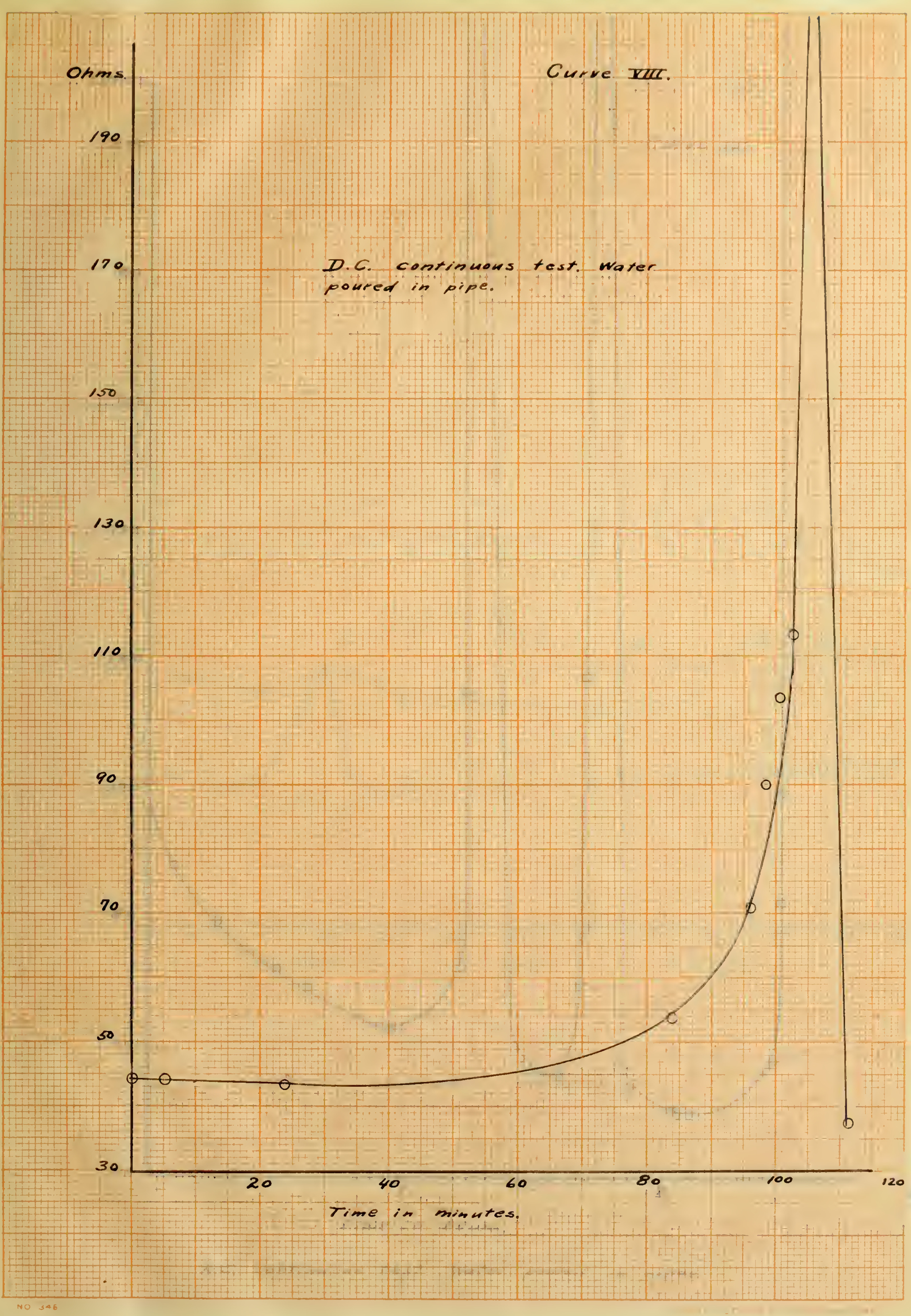


Curve II
Ohms
Curve showing effect of use of continuous direct current.
Time in hours

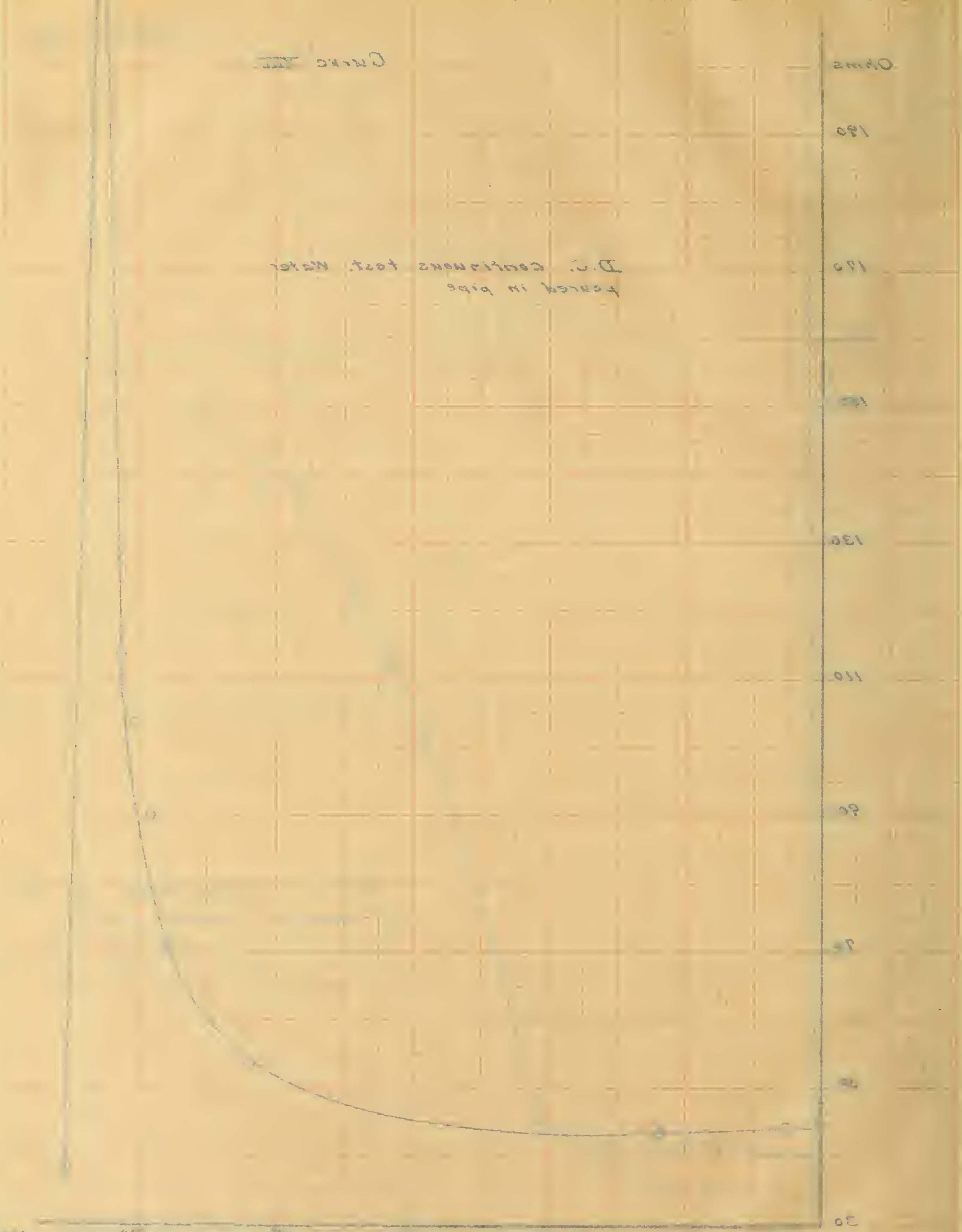

Curve VII.
Ohms.
480
400
320
240
160
80
1
2
3
Time in hours.
Curve showing effect of use of continuous direct current.

Curve XII

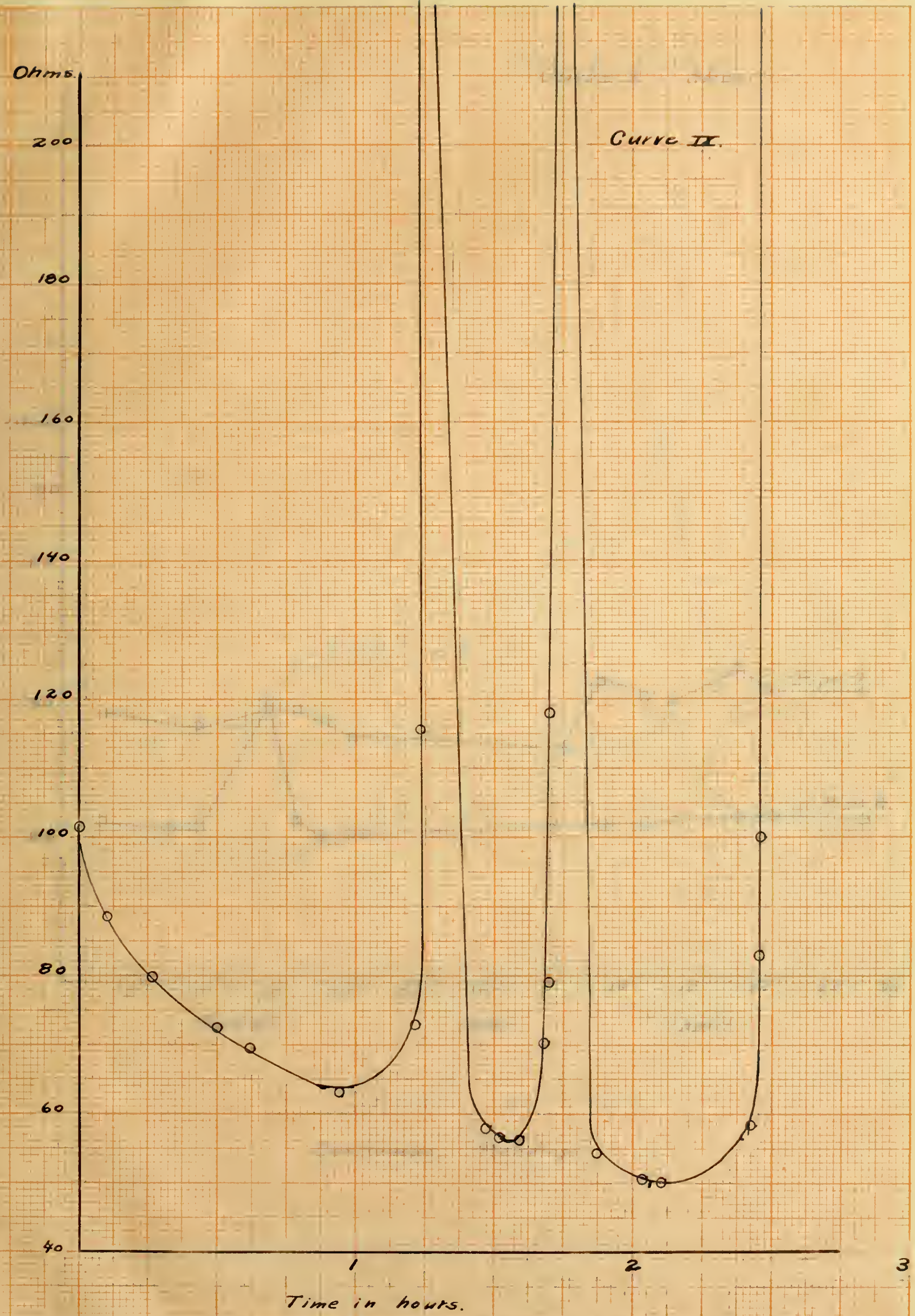

Ohms
480
400
320
240
160
80
3
2
1
Time in years
Curve showing effect of use
of continuous direct current.



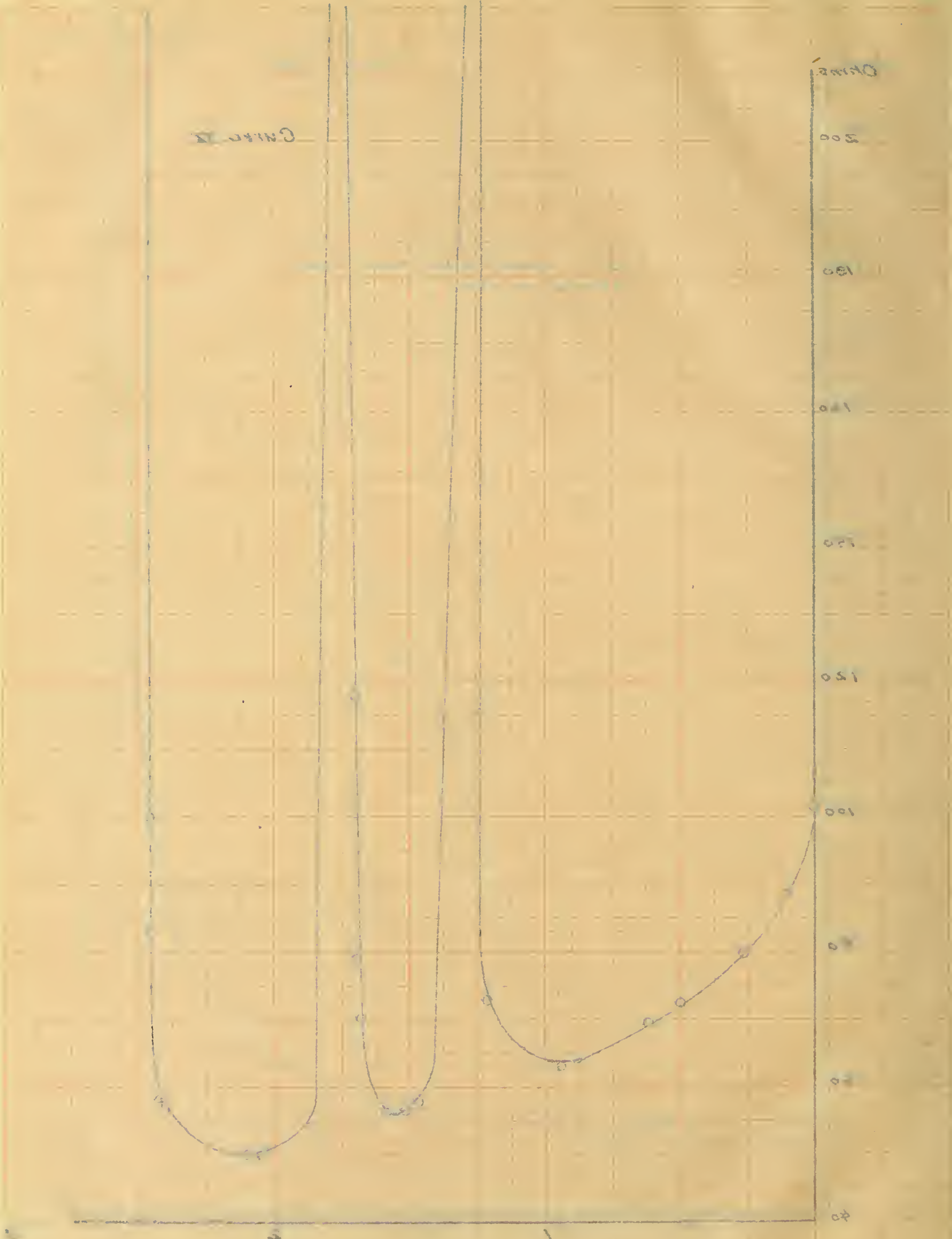
Ohms.
Curve VIII.
190
170
D.C. continuous test. Water poured in pipe.
150
130
110
90
70
50
30
20
40
60
80
100
120
Time in minutes.
NO 345



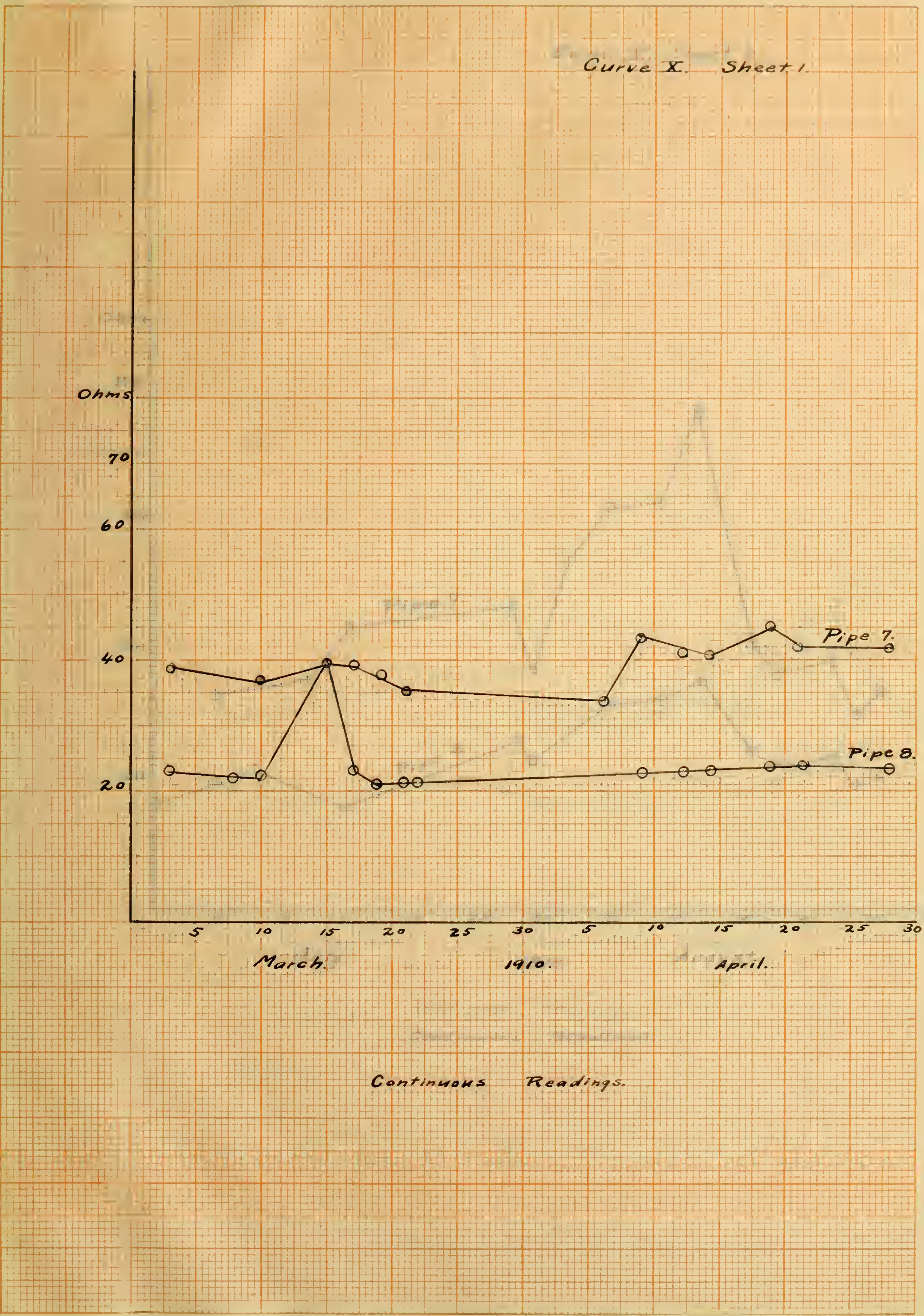
Curve III
D.C. Continuous test. Water poured in pipe
Ohms
Time in minutes



A.C. continuous test. Water poured in pipes.



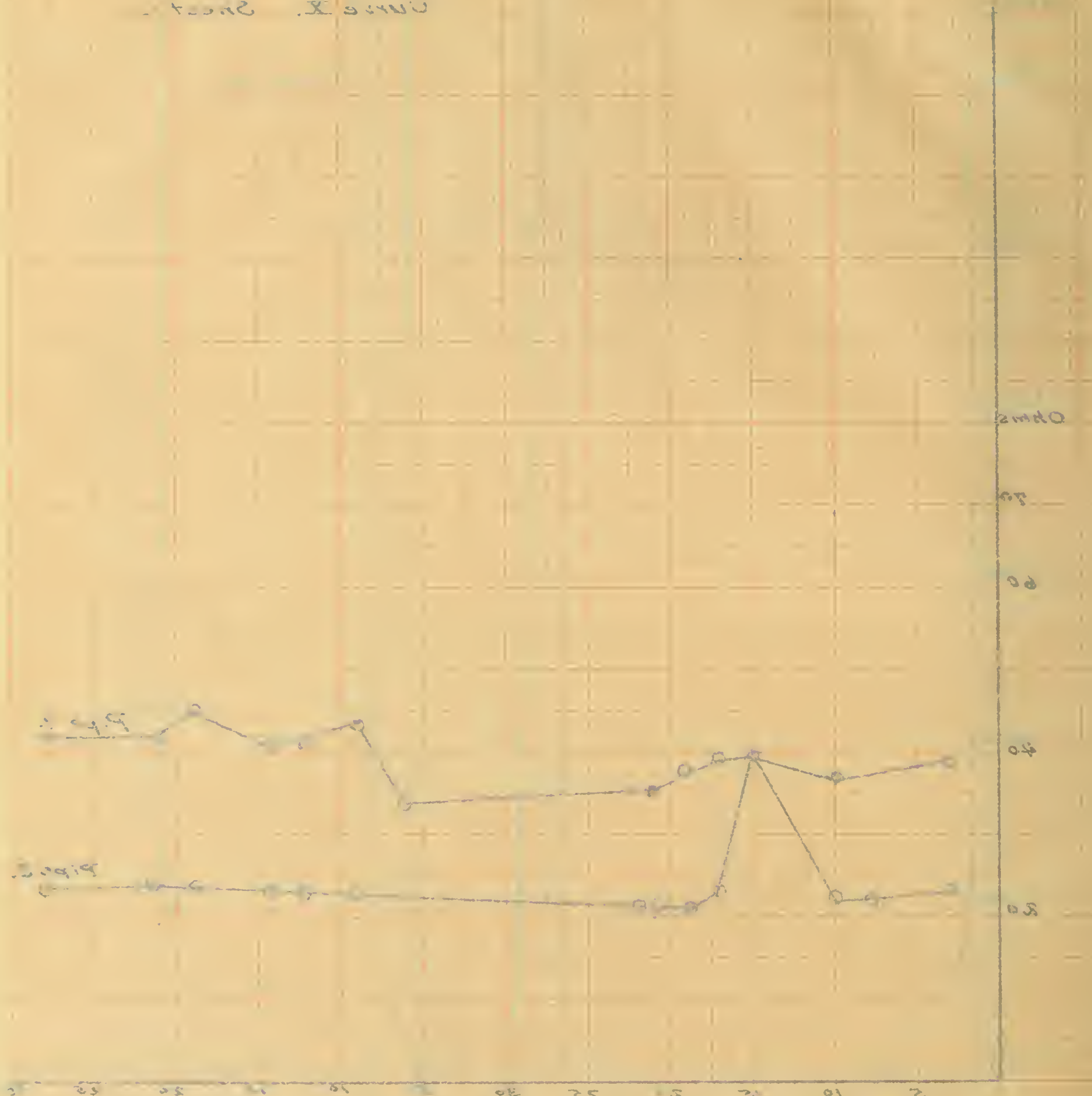
A.C. continuous test. Water ... in pipes.



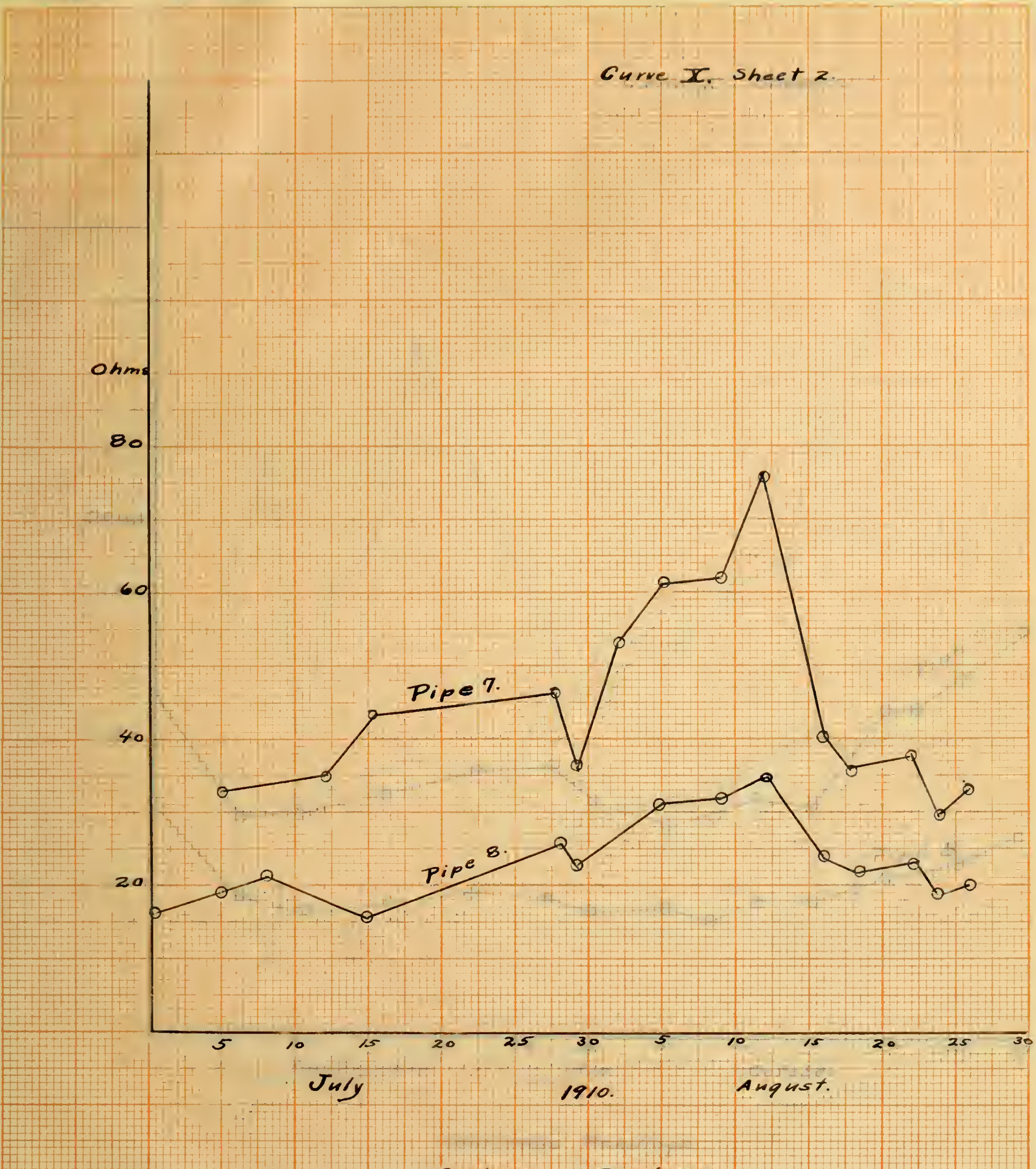
Curve X. Sheet 1.
Ohms
70
60
40
20
Pipe 7.
Pipe 8.
5
10
15
20
25
30
5
10
15
20
25
30
March.
1910.
April.
Continuous Readings.

NO 346

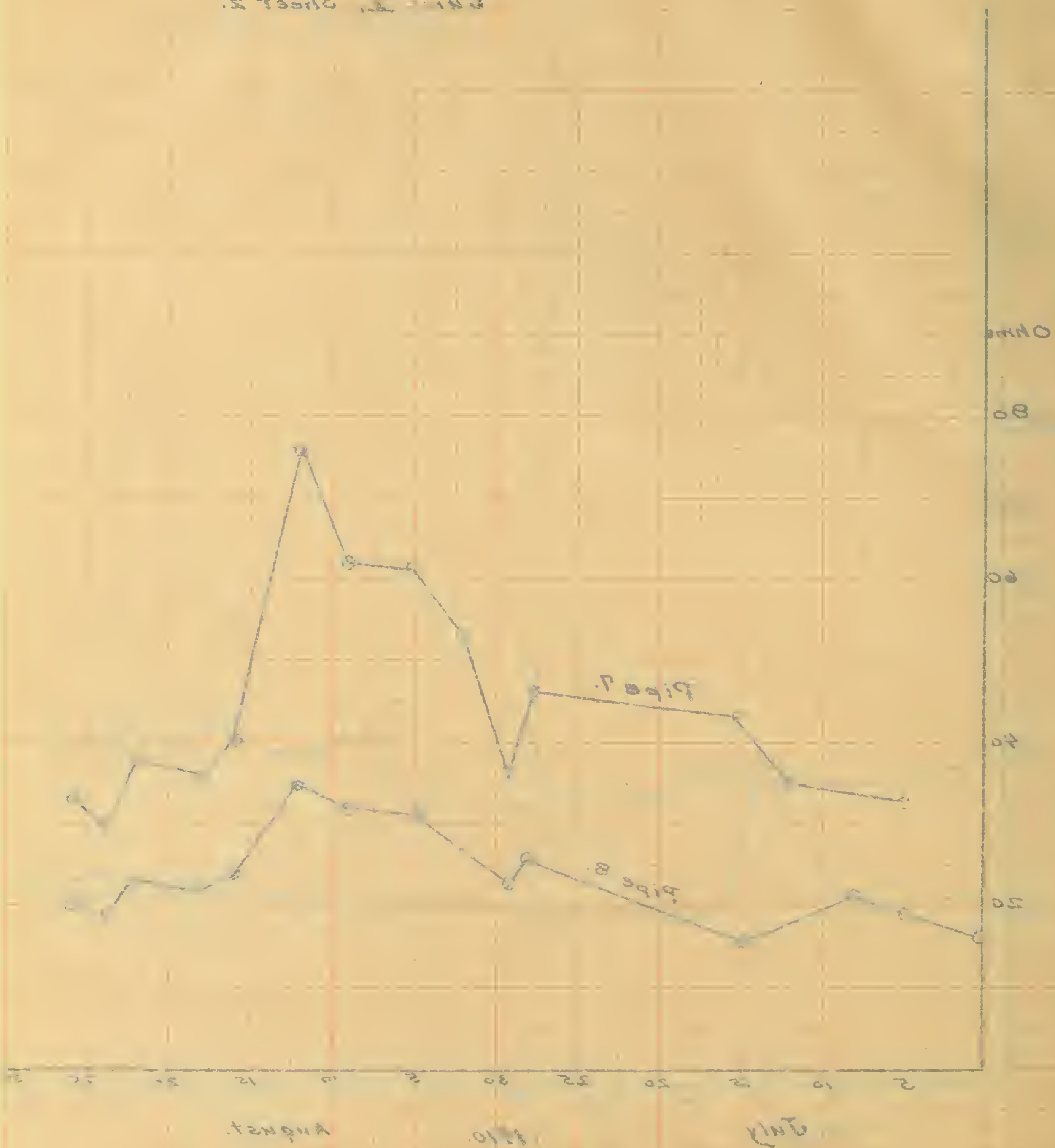
Curve X. Sheet 1.



Continuous Readings

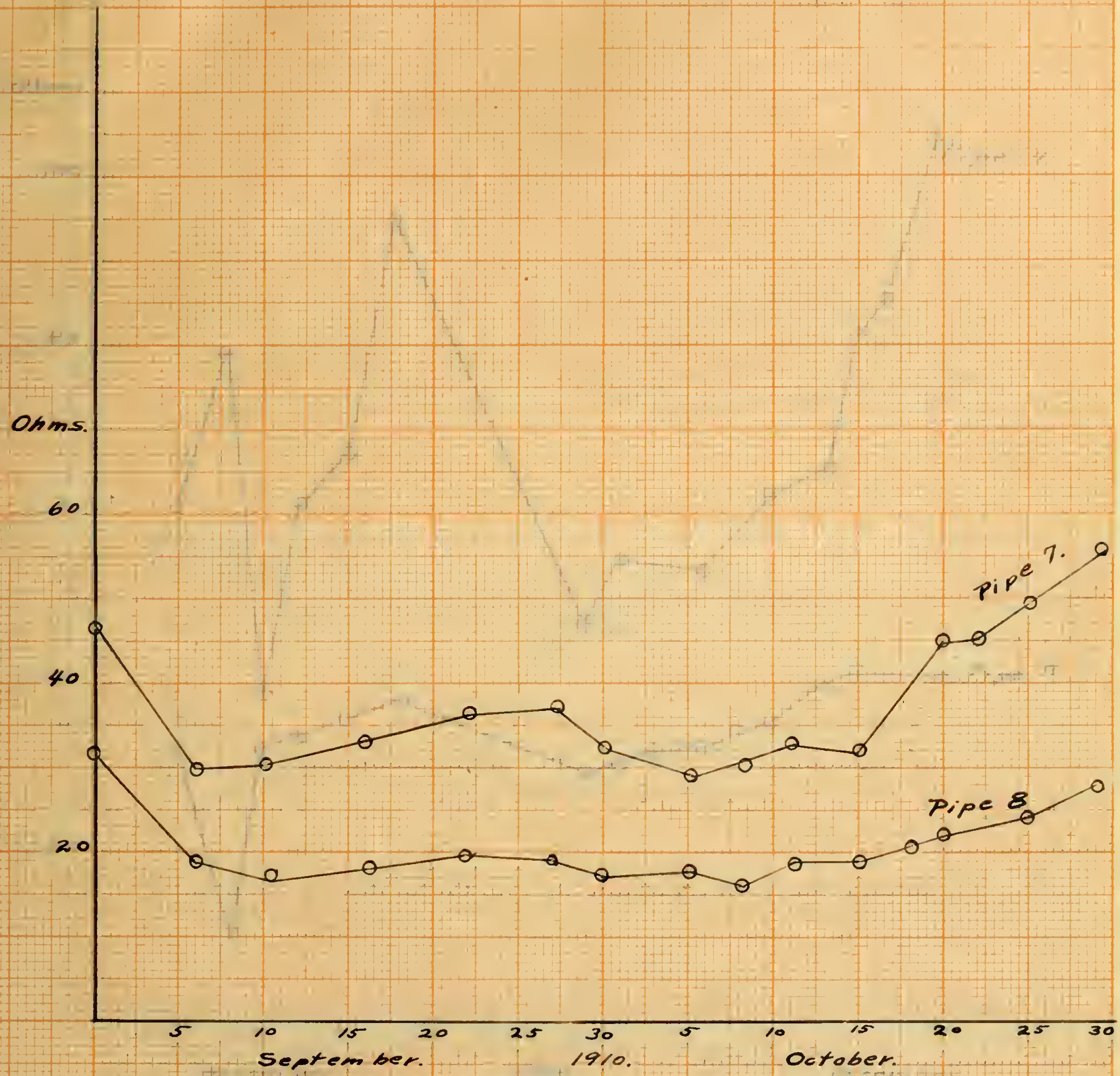

Curve X. Sheet 2.
Ohms
80
60
40
20
Pipe 7.
Pipe 8.
5
10
15
20
25
30
5
10
15
20
25
30
July
1910.
August.
Continuous Readings.

Curve E, Sheet 2.



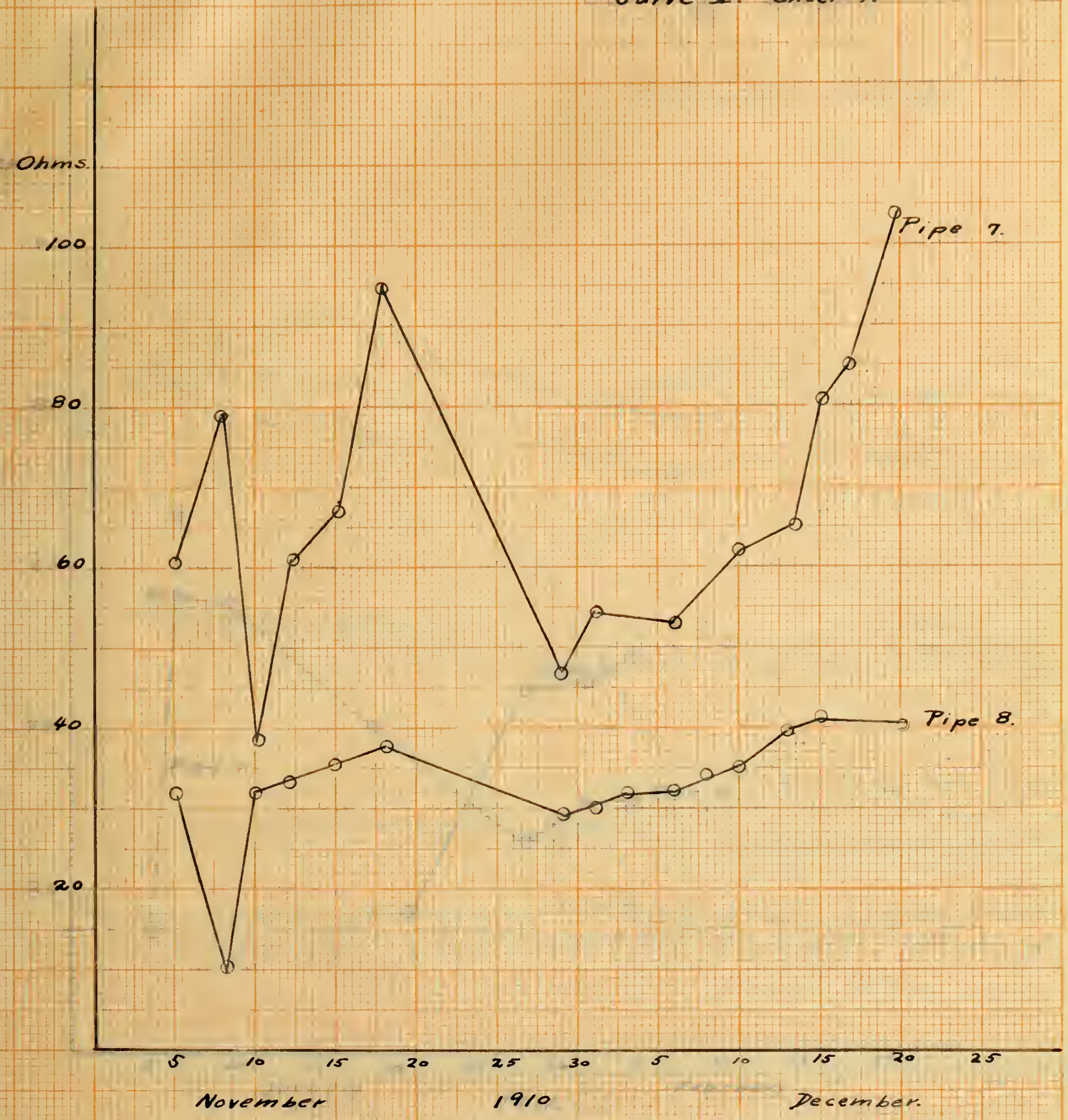
Continuous Testing.

Curve X. Sheet 3.



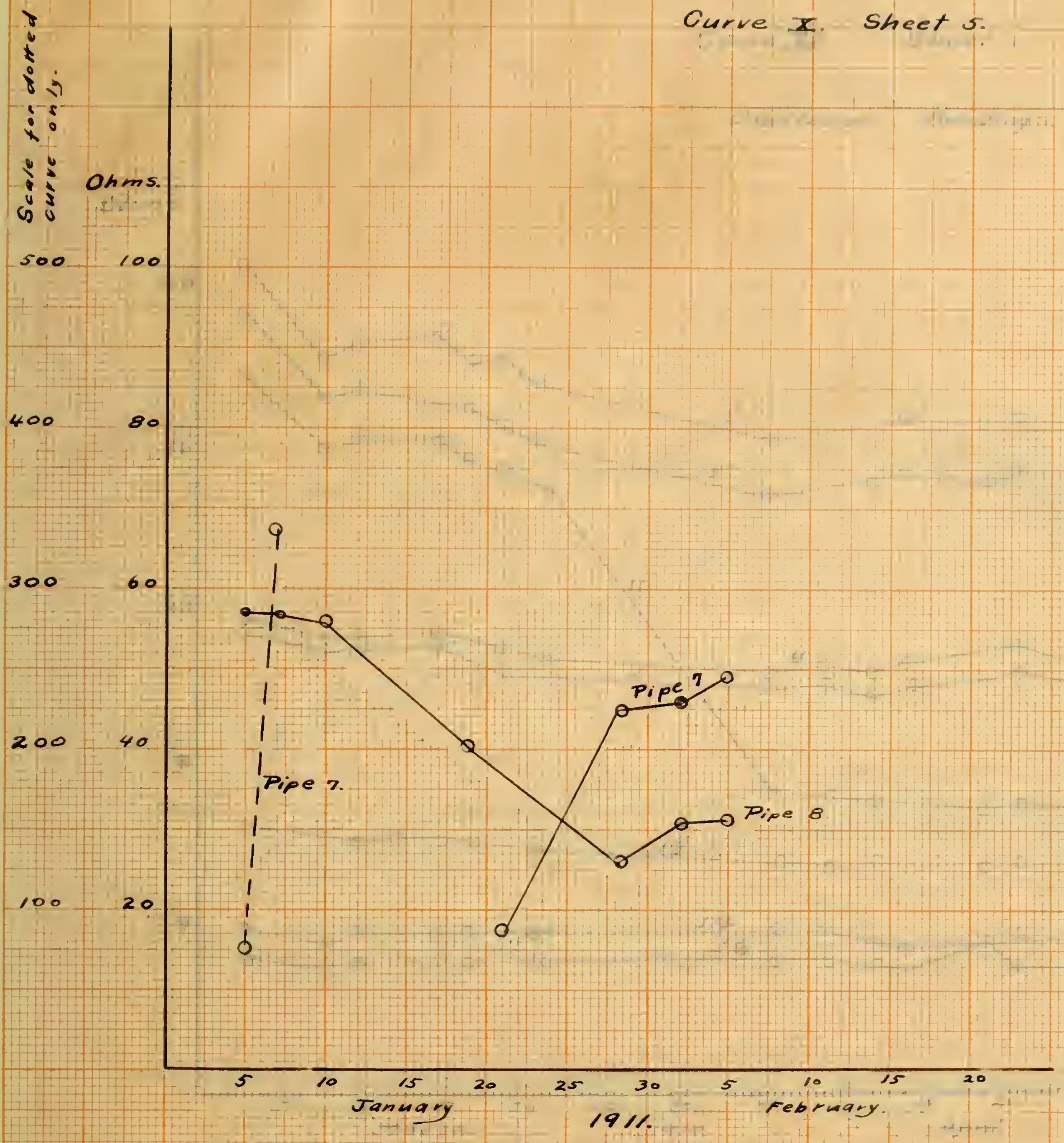
Continuous Readings.

Curve X. Sheet 4.

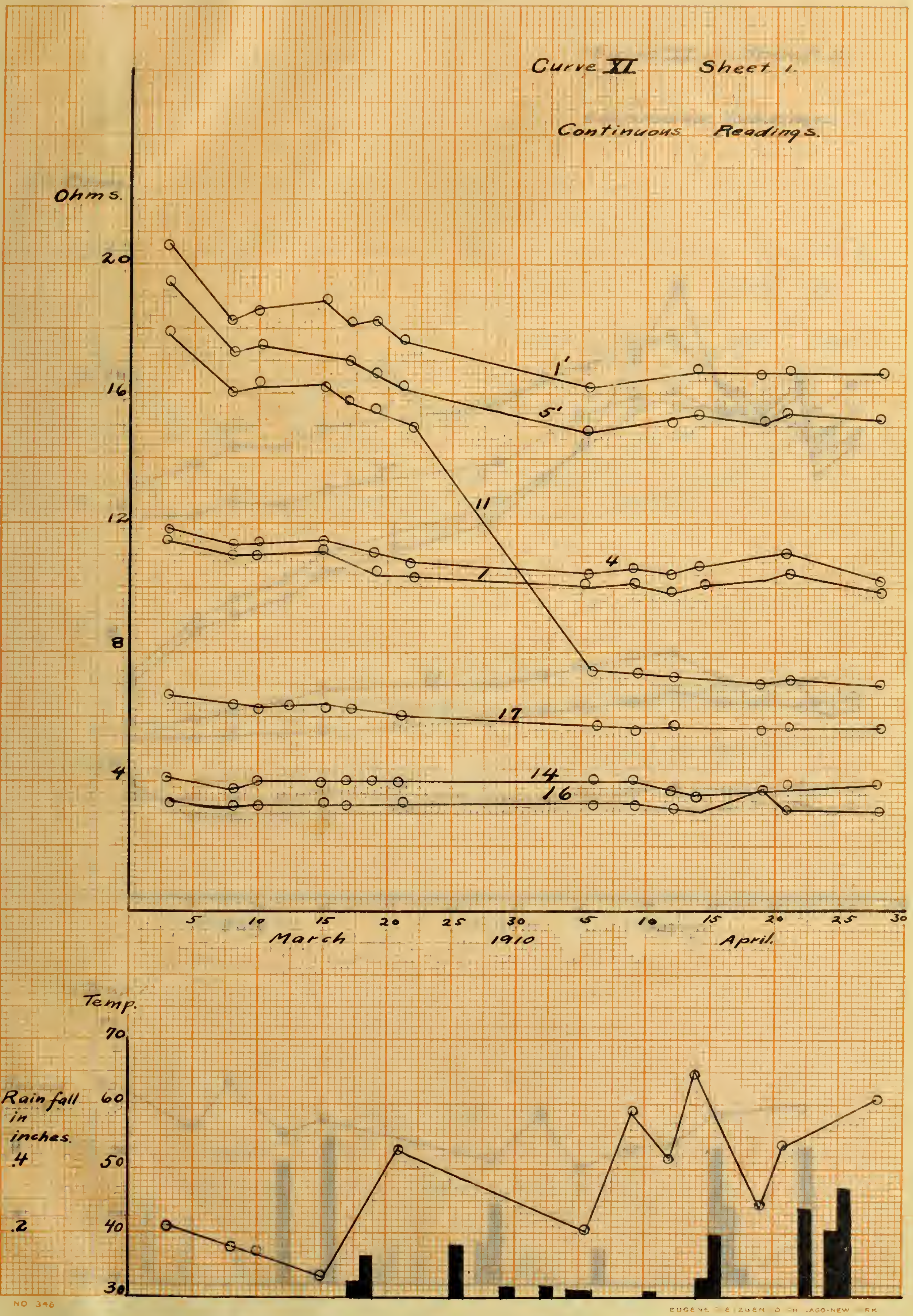


Continuous Readings.

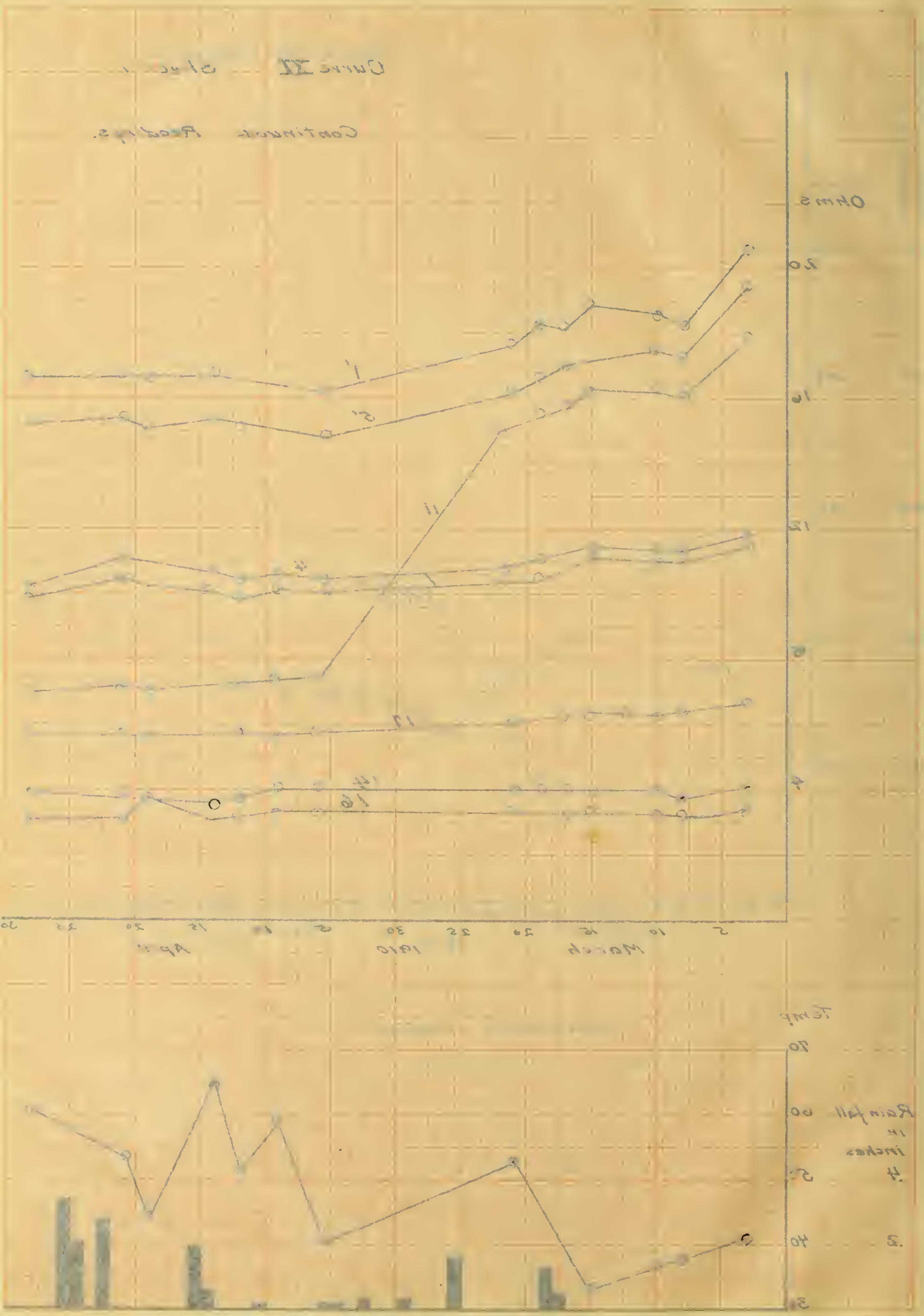
Curve X. Sheet 5.

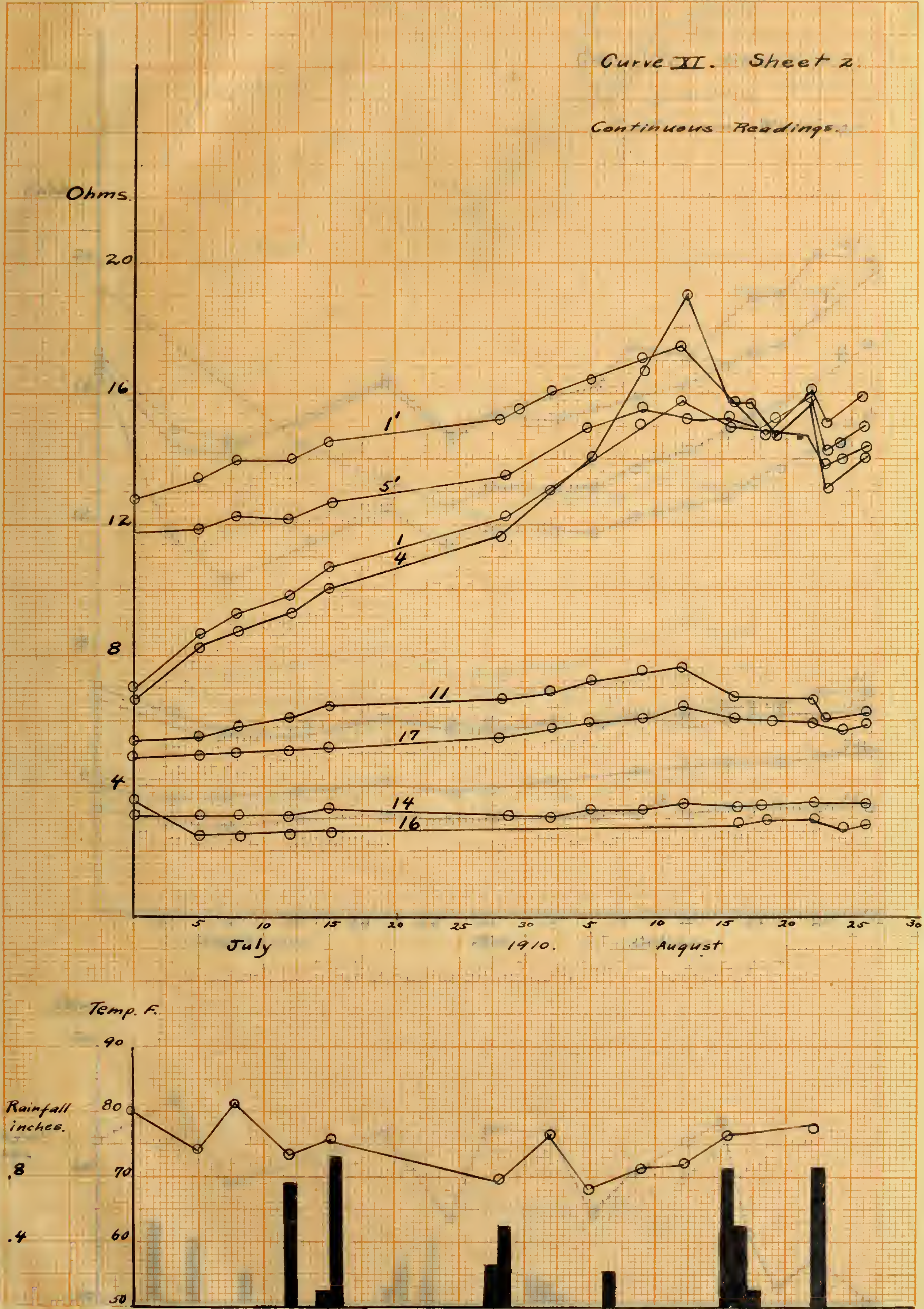


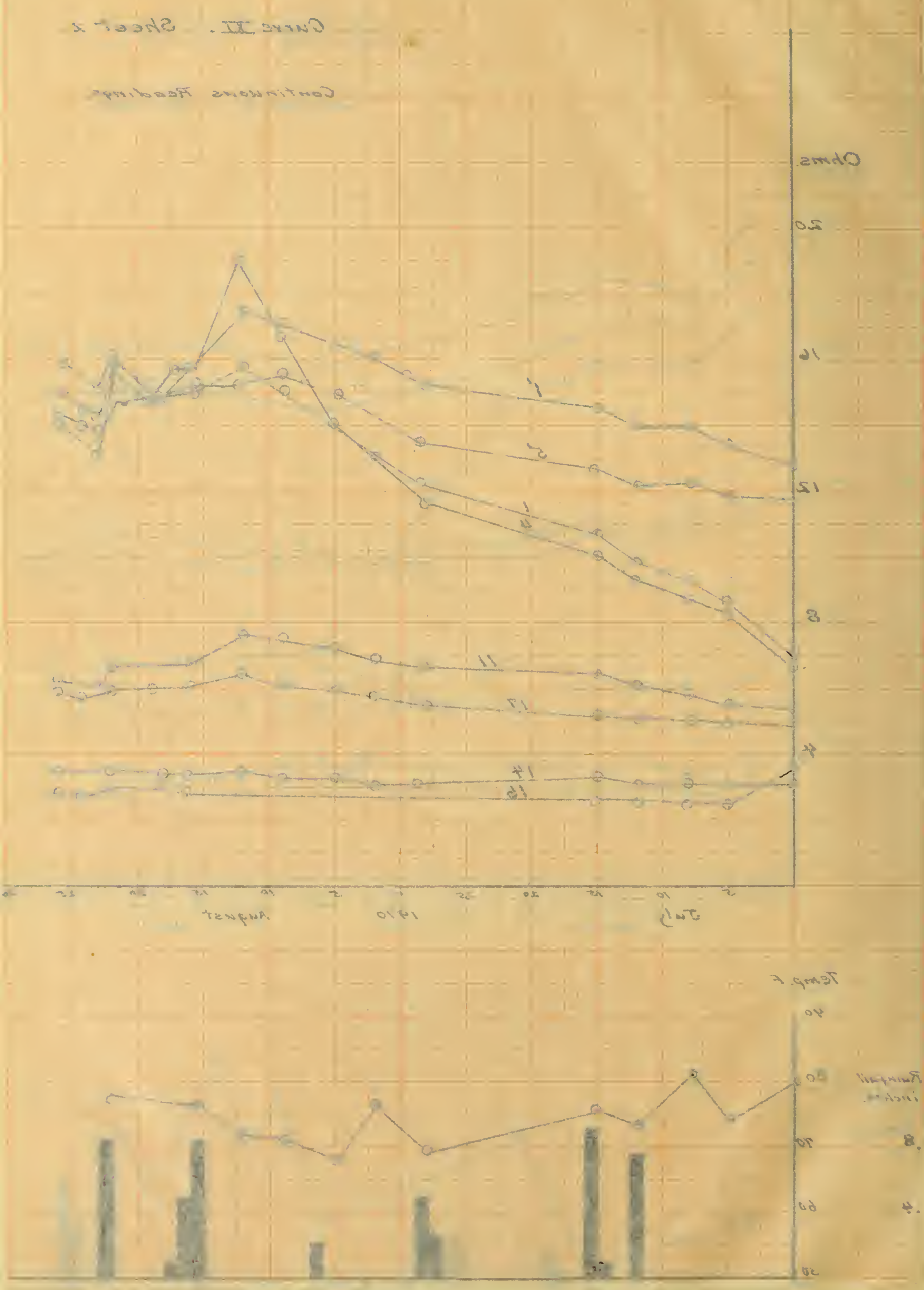
Continuous Readings.



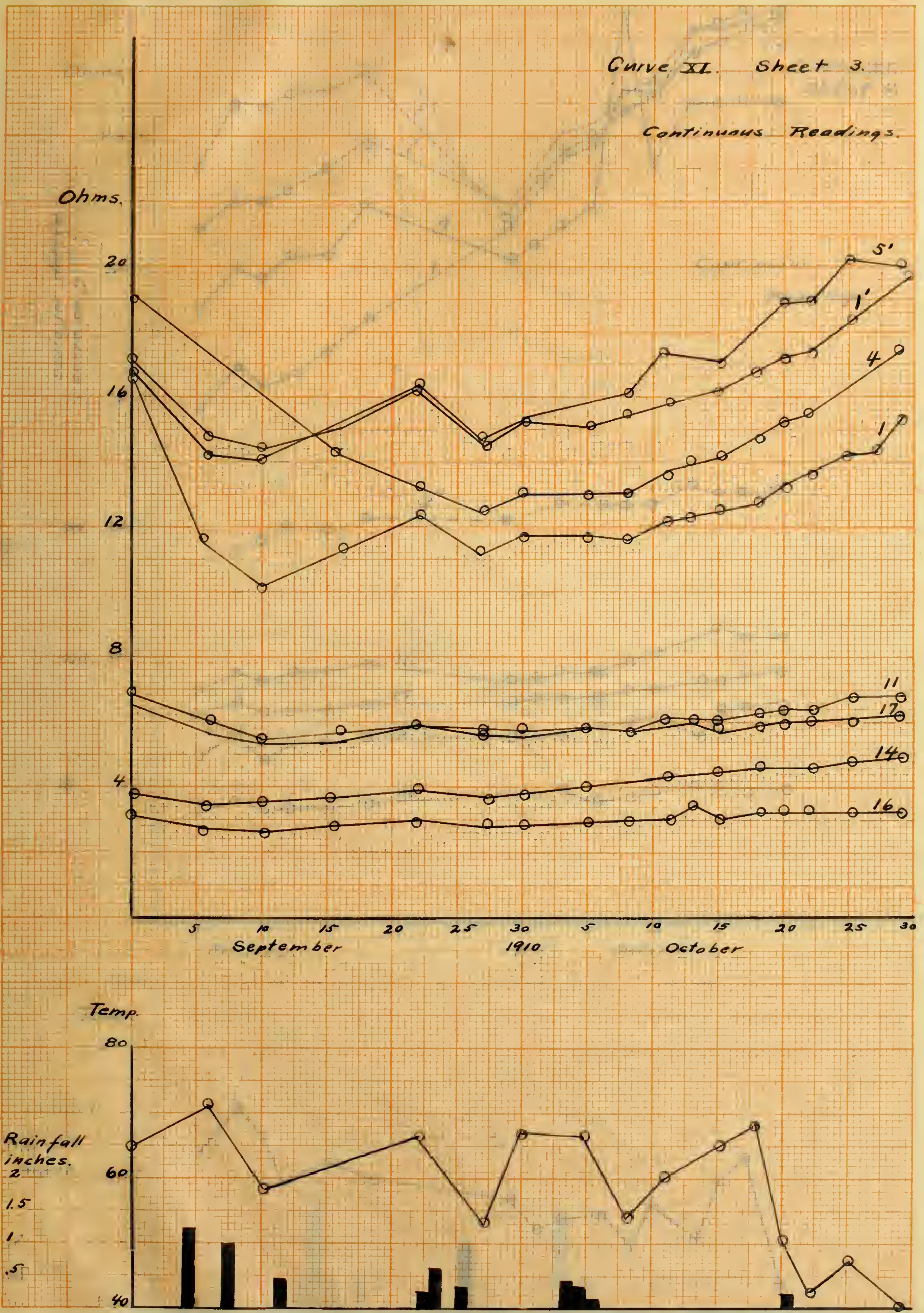
Curve XI Sheet 1.
Continuous Readings.
Ohms.
20
16
12
8
4
1'
5'
11
4
1
17
14
16
5
10
15
20
25
30
5
10
15
20
25
30
March
1910
April.
Temp.
70
60
50
40
30
Rain fall in inches.
.4
.2
NO 345
EUGENE DIETZGEN CO. CHICAGO-NEW YORK


Continuous Readings
Ohms
March
1910
April
Temp
Rainfall in inches


Curve XI. Sheet 2.
Continuous Readings.
Ohms.
20
16
12
8
4
1'
5'
1
4
11
17
14
16
5
10
15
20
25
30
5
10
15
20
25
30
July
1910.
August
Temp. F.
90
80
70
60
50
Rainfall inches.
.8
.4



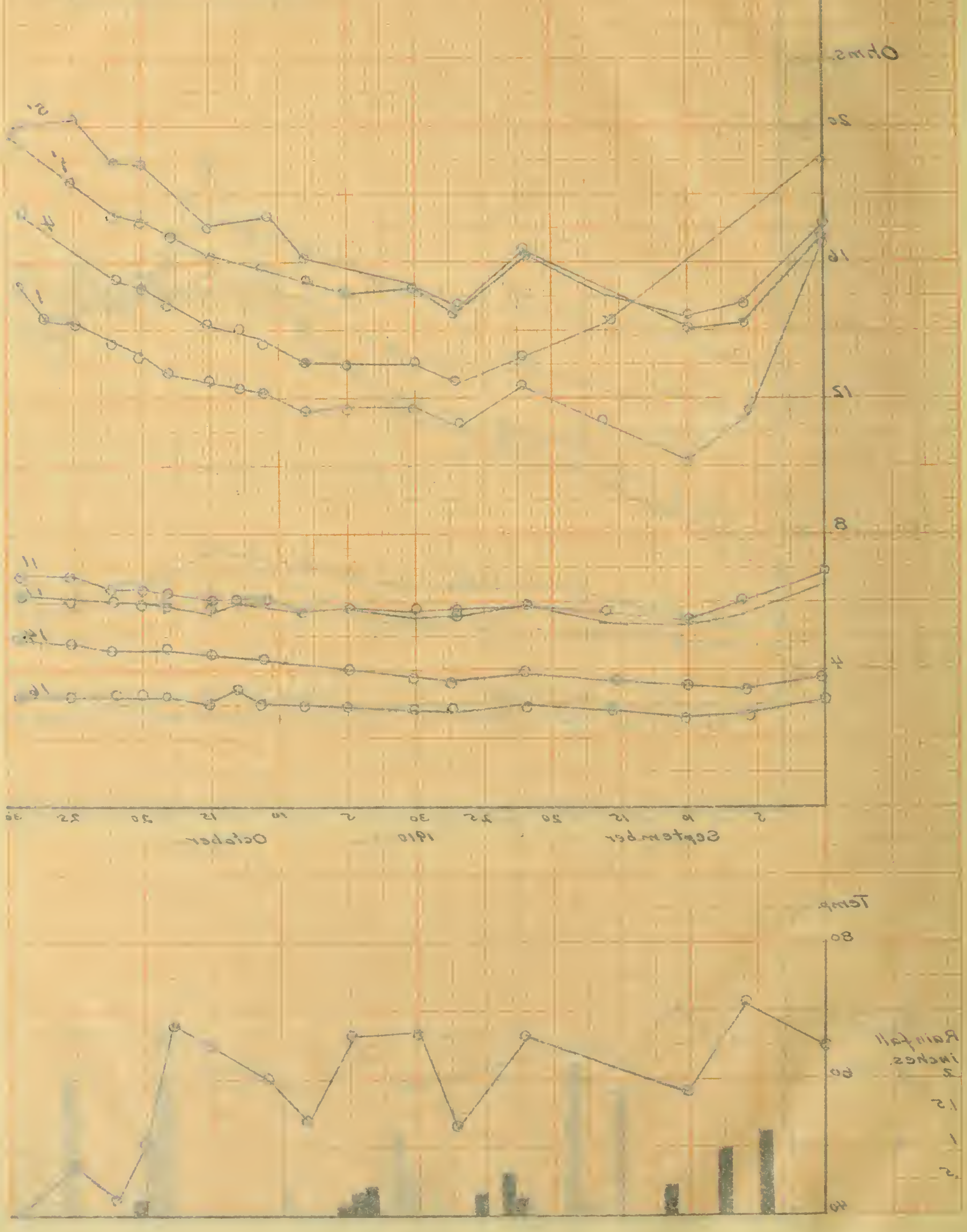
Curve II. Sheet 2
Continuous Readings
Ohms
20
16
12
8
4
August
1910
July
Temp. F
90
80
70
60
50
Rainfall inches
.8
.4

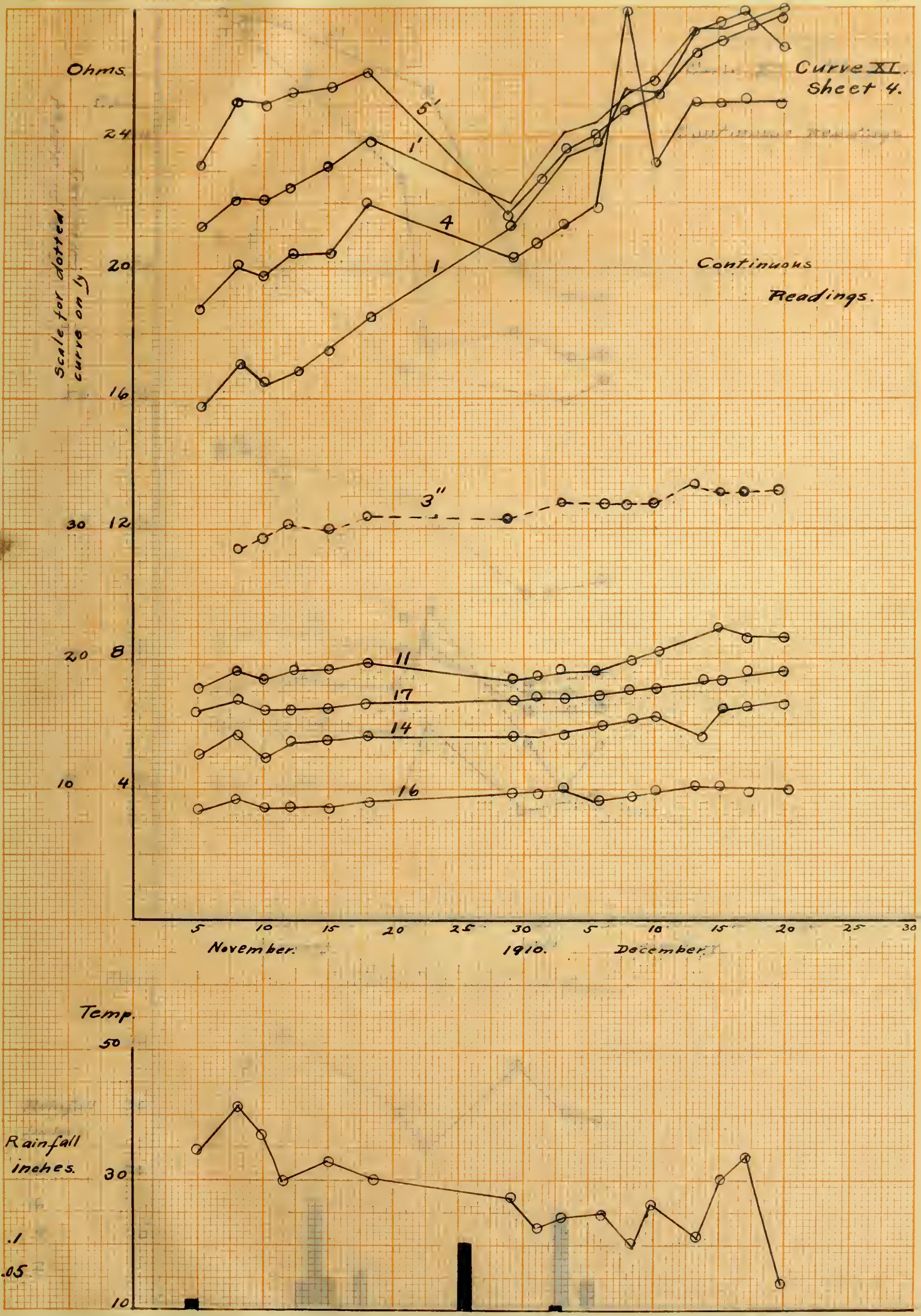


Curve XI. Sheet 3.
Continuous Readings.
Ohms.
20
16
12
8
4
5'
1'
4
1
11
17
14
16
5
10
15
20
25
30
5
10
15
20
25
30
September
1910
October
Temp.
80
60
40
Rainfall inches.
2
1.5
1
.5

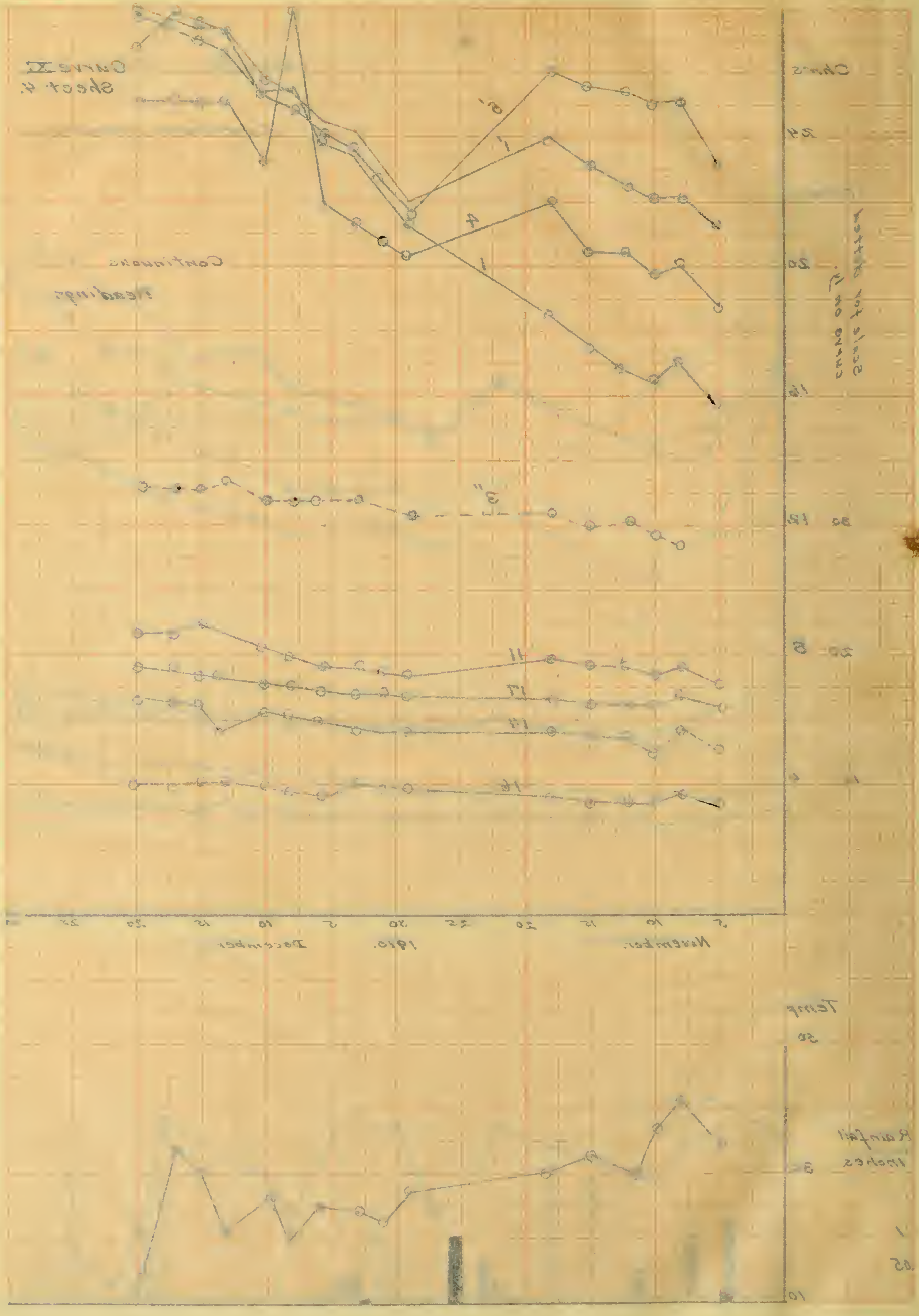
Curve XI Sheet 3.

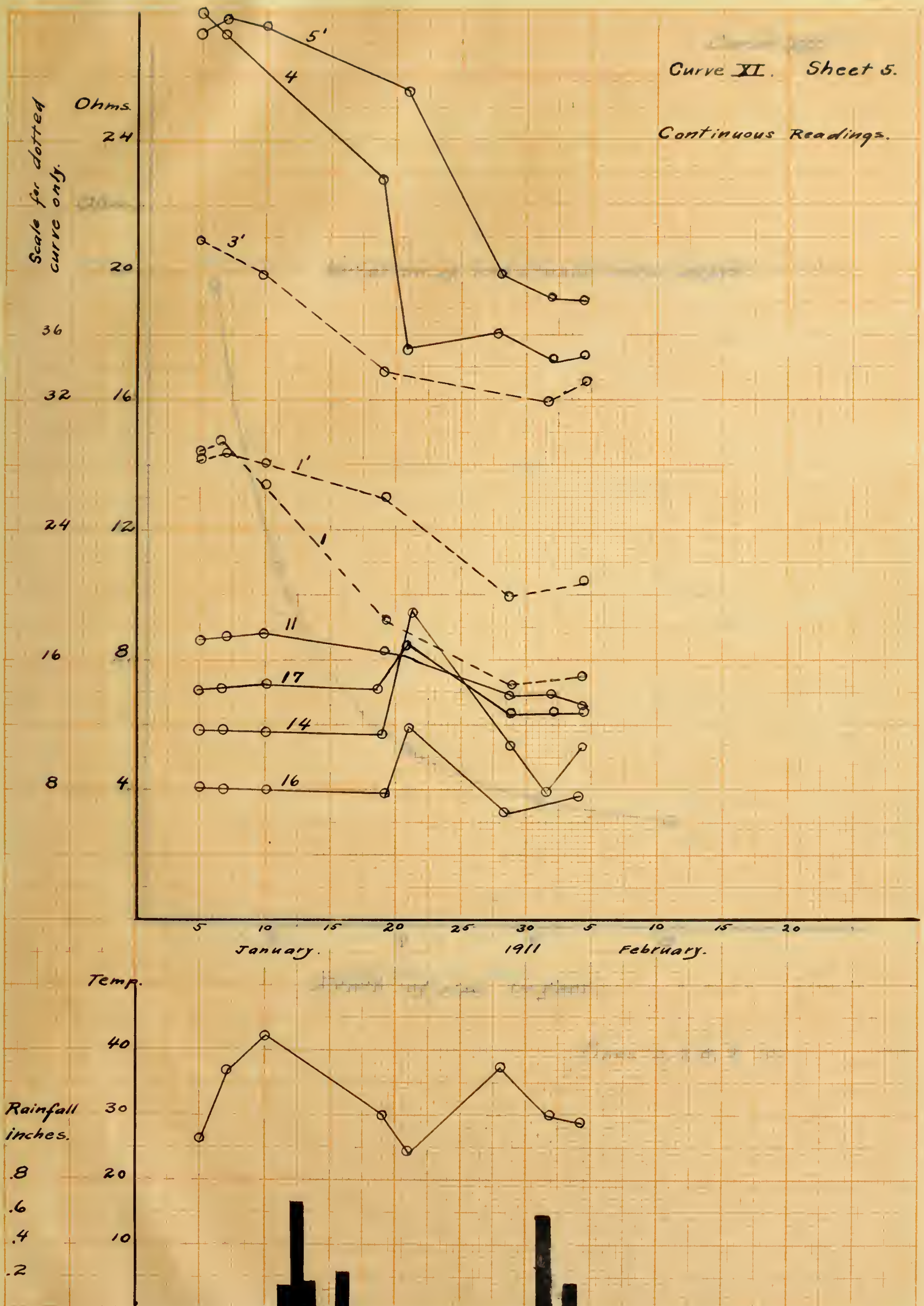
Continuous Readings.



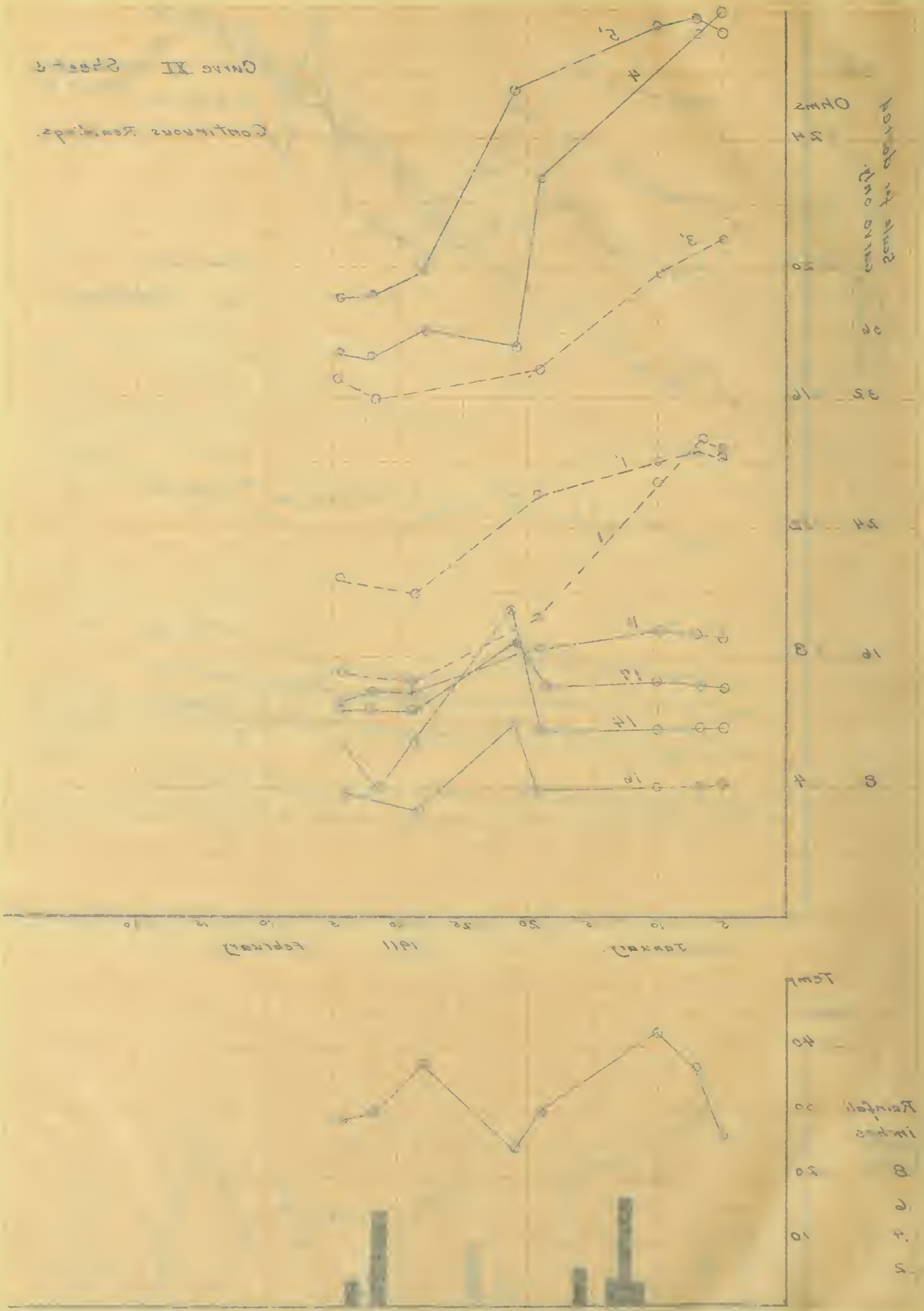


Curve XI.
Sheet 4.
Ohms.
Scale for dotted curve only.
5'
1'
4
1
3"
11
17
14
16
24
20
16
30 12
20 8
10 4
Continuous
Readings.
5
10
15
20
25
30
5
10
15
20
25
30
November.
1910.
December.
Temp.
50
30
10
Rainfall
inches.
.1
.05

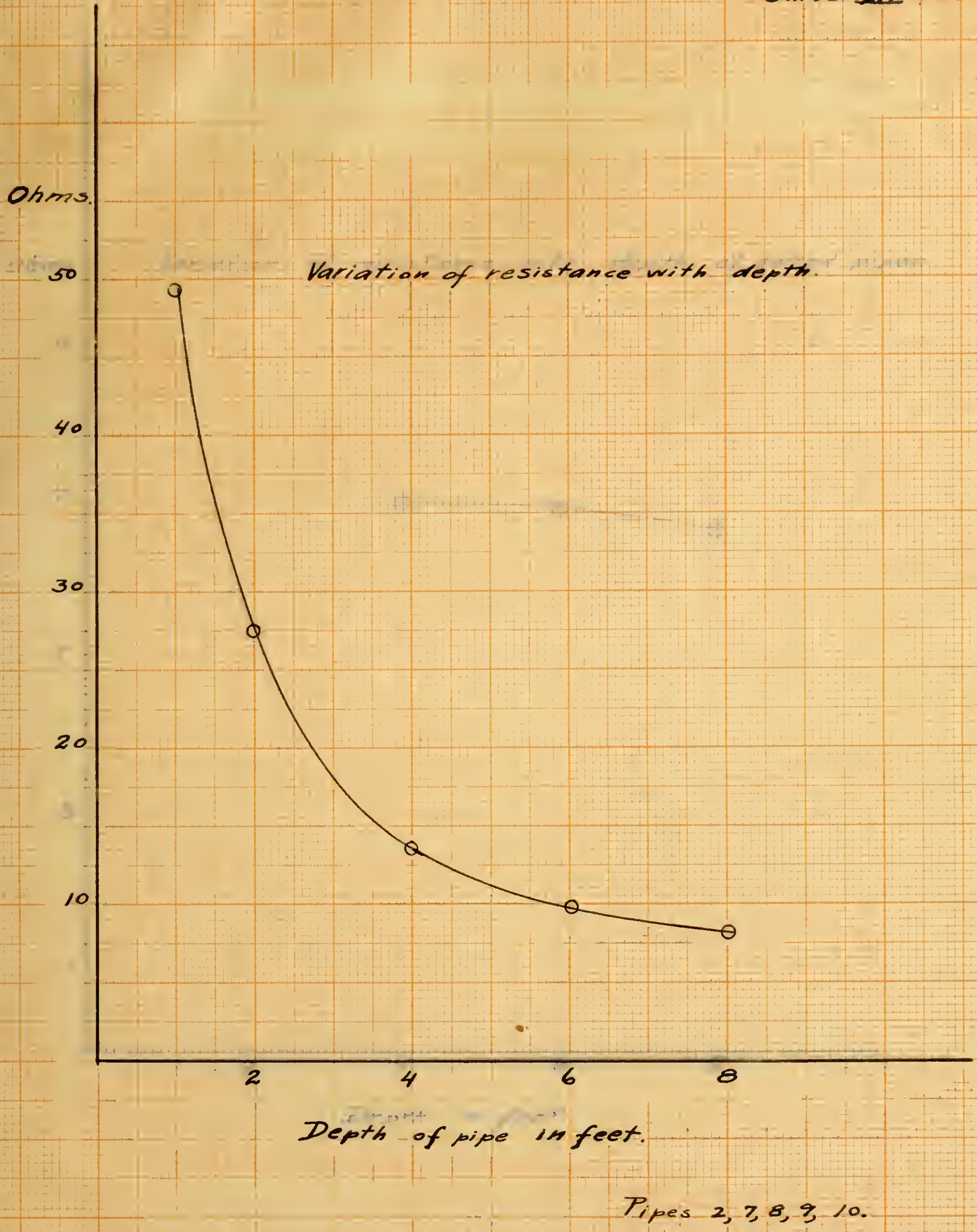

Curve XI
Sheet 4.
Continuous readings
Chains
24
20
16
12
8
4
November.
1910.
December
Temp
50
Rainfall
inches

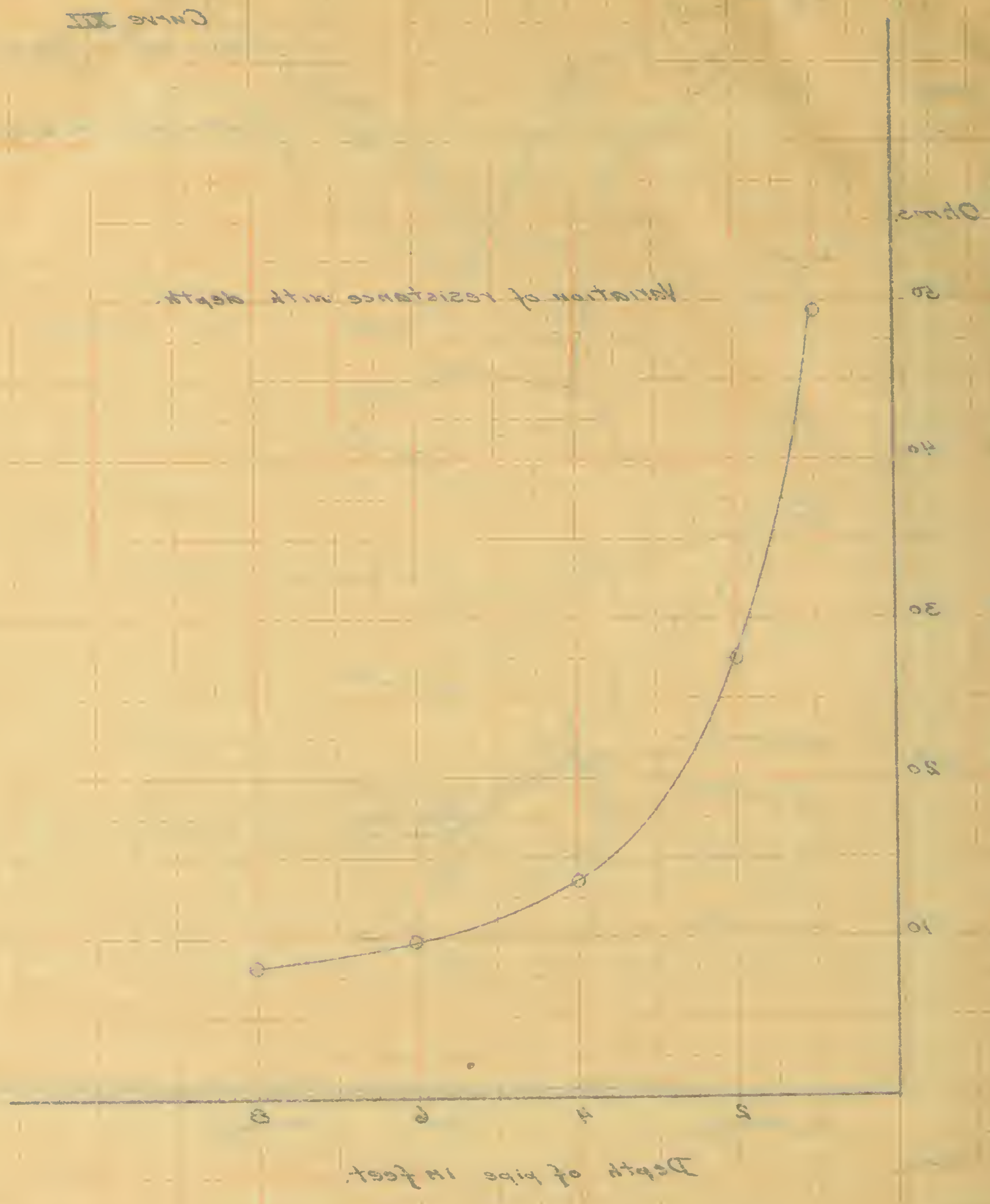


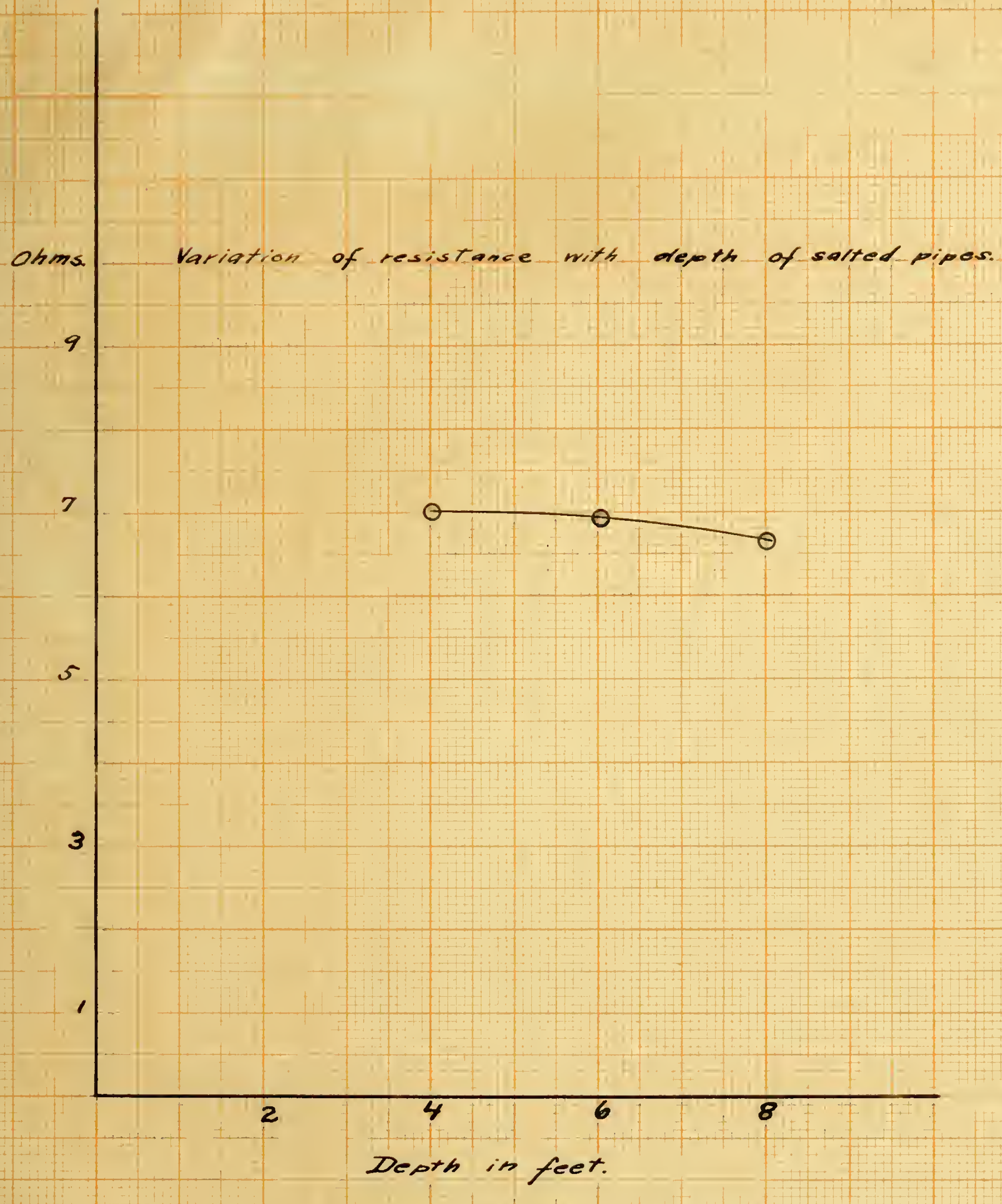
Curve XI. Sheet 5.
Continuous Readings.
Ohms.
Scale for dotted curve only.
24
20
36
32
16
24
12
16
8
8
4
5'
4
3'
1'
1
11
17
14
16
5
10
15
20
25
30
5
10
15
20
January.
1911
February.
Temp.
40
30
20
10
Rainfall inches.
.8
.6
.4
.2



Curve XI Sheet 6
Continuous Readings.
Ohms
Scale for dotted curve only.
January
1911
February
Temp
Rainfall inches


Ohms.
50
40
30
20
10
Variation of resistance with depth.
2
4
6
8
Depth of pipe in feet.
Pipes 2, 7, 8, 9, 10.


Curve XII
Variation of resistance with depth.
Ohms.
50
40
30
20
10
2
4
6
8
Depth of pipe in feet.
Pipes 2, 7, 8, 9, 10.


Ohms.
Variation of resistance with depth of salted pipes.
9
7
5
3
1
2
4
6
8
Depth in feet.